Naval Research Laboratory

Washington, DC 20375-5000 NRL Memorandum Report 5805 June 24, 1986

(2)

The Use of HF Surface Wave Propagation to Support a Data Link From an Expendable Buoy

E. L. ALTHOUSE AND M. A. GRIMM

Transmission Technology Branch
Information Technology Division

86 8 14 00

AD-A170966

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b DECLASSIFICATION/DOWNGRADING SCHEDULE	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release, distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NRL Memorandum Report 5805	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Research Laboratory 6b. OFFICE SYMBOL (If applicable) Code 7550	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Washington, DC 20375-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION SPAWARSYSCOM 8b. OFFICE SYMBOL (If applicable) PDW110-32	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20360	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62721N PROJECT NO. 75-0239-0-6 TASK NO RX21.222D WORK UNIT ACCESSION NO. DN 280-181

11. TITLE (Include Security Classification)
The Use of HF Surface Wave Propagation to Support a Data Link from an Expendable Buoy

12. PERSONAL AUTHOR(S)
Althouse, E. L. and Grimm, M. A.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 10/1/84 TO 9/30/85	24 June 1986	85

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	HF Surface wave HF propagation Expendable buoys

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The use of HF surface wave propagation is analyzed at frequencies of 3, 5, 7 and 10 MHz for its ability to support a moderate rate data link between an ocean deployed, expendable buoy and a quiet surface platform at ranges of 185 to 370 km (100 to 200 nmi). It is assumed that the maximum size antenna that can be supported by the buoy is a monopole of 5 meters length and 0.2 meter thickness. A mathematical model, which includes a tradeoff between bandwidth and efficiency, is used to estimate the power loss in the matching network to the buoy antenna. Estimates of the additional loss caused by the antenna bobbing in the water are given. The estimates of propagation loss as a function of frequency and sea state were taken from Barrick's publications, and atmospheric noise was estimated from CCIR report 322.

Predictions of the RF driver power required for the expendable buoy system are given as a function of time of day for the locations of Cuba (low latitude, high noise example) and the Bering Strait (high latitude, low noise example). The predicted power requirements should be considered to represent a lower bound to the actual requirement in a real ocean environment. An additional margin of at least 6 dB should be added to

(Continues)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL E. L. Althouse	22b. TELEPHONE (Include Area Code) (202) 767-2586 22c. OFFICE SYMBOL Code 7553

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

i

19. ABSTRACT (Continued)

account for additional loss caused by the antenna bobbing in moderate to rough sea states. Optimum performance for the expendable buoy system was found to occur in the range of 3 to 7 MHz depending upon range, geographical location (noise characteristics), and sea state. Near the Bering Strait geographical locations, a data rate of 2400 bits/sec can be supported over a range of 185 km during all hours of the day and all seasons of the year with less than 5 watts of power at 3 MHz and less than 1 watt at 5 MHz. At a range of 278 km, 18 watts are required at 3 MHz and 6 to 7 watts are required at 5 MHz. Ignoring the antenna bobbing effect, the predicted driver power is insensitive to sea state at 3 MHz and below. At 5 MHz a sea state of 6 increases the power requirement to 22 watts for a 278 km range. For contrast, the power requirements near the noisier Cuba locations are as follows. At a range of 185 km, 1900 watts are required at 3 MHz and 151 watts at 5 MHz (sea state 0). At a range of 278 km, 7560 watts are required at 3 MHz and 1470 watts at 5 MHz (sea state zero). The power requirements are strongly dependent upon time of day and season of the year. Noise levels are highest during the nighttime hours and may decrease by two or three decades during the middle of the daylight hours at frequencies of 3 to 5 MHz.

Communications over the ranges of interest are feasible most of the time at low noise sites such as those found at moderate to high latitude. However, in high noise regions, which are usually found at lower latitudes such as Cuba, communications will be possible only at extremely low data rate or only during limited periods of the daylight hours (when the diurnal noise variation is near its minimum) and when the seasonal noise is at its minimum.

CONTENTS

THE USE OF HF SURFACE WAVE PROPAGATION TO SUPPORT A DATA LINK FROM AN EXPENDABLE BUOY

I. INTRODUCTION

Expendable buoys are used frequently by military and civilian agencies for gathering oceanographic and acoustic data in situations where manned platforms are not economical or otherwise desirable. For some applications the information gathered is small and timeliness is sufficiently unimportant that the data can be recorded onboard the buoy and transferred to the host upon physical recovery of the buoy. For most applications, however, both timeliness and the magnitude of data involved require that a dependable data link be available between the buoy and its host. The host could be a shore-based station, a marine vessel, an aircraft, etc. Our interest in communication links between expendable buoys and support hosts was stimulated by a specific application that requires linkage between a buoy and a surface ship; consequently, the emphasis in this report will be on a communication method that satisfies this particular requirement. Methods of establishing the data link to an airborne host were not of interest, except in the case where the airborne platform was used as an intermediate relay. To avoid classification sensitivity, details about the specific application will not be discussed.

Many applications have requirements of data rates ranging from 1 to 10 kilobits/sec and ranges up to 200 nautical miles. Reliable communications at these ranges and data rates are difficult to achieve with limited power and realestate. Size, weight, center of gravity, and positional stability restrictions associated with the use of a buoy (usually a spar buoy) have a strong impact on the capability of any RF communication system selected. Poor positional stability (such as rolling and pitching) will have the strongest effect on very high frequency methods of communication (such as microwave, EHF, and optical) where antenna directional gain introduces severe beam-steering requirements; size, weight, and center of gravity constraints will have the strongest effect on lower frequency methods when efficient antenna structures become large. The size of the buoy also controls the total amount of energy available to accomplish the mission, including the supply of power for buoy electronics and RF transmission. Frequency ranges that may appear to be optimal from the standpoint of compatibility of antenna size and steering requirements are generally not well suited for ranges beyond line-of -sight.

Surface-wave propagation, in which the propagating wave is constrained in the vertical dimension to follow the air/water or air/land interface, is well supported in the buoy environment near the lower end of the HF band (3 - 30 MHz). Resonant antennas (e.g. quarter wavelength monopole) for the low end of the HF range are too large to be supported stably by reasonably sized buoys (e.g. 0.6 m diameter by 3 m length). Consequently, it is reasonable to expect that system performance may be

Manuscript approved April 24, 1986.

optimal at a frequency above that expected from propagation characteristics alone and below that at which the buoy can support a resonant antenna. The objective of this report is to consider all factors that influence the performance of the expendable buoy RF data link, determine an optimum mode of operation, and characterize the projected performance. Although surface-wave propagation will be the only method analyzed in detail in this report, the advantages and disadvantages of other candidate methods are discussed briefly in the following paragraphs.

Alternate methods of providing an RF data link such as satellite relay, non-satellite relay (via balloon, kite, or remotely piloted vehicle instrumentation), VHF meteor burst, VHF/UHF tropospheric scattering, and HF sky wave have been considered in some detail in a report by Booz-Allen & Hamilton, Inc. for offboard sensor systems [1]. The result of the Booz-Allen study was the recommendation of the use of a balloon or kytoon (wing shaped balloon) supported relay; however, the link power budget was favorable only when the relay could be positioned approximately midway (in a lateral sense) between the ends of the link. Since unfavorable winds will prevent appropriate placement of the relay platform (free balloon, or kite), this method of providing a data link was rejected for our application. The use of a remotely piloted vehicle (RPV) containing a relay was also ranked (by Booz-Allen) as an attractive solution to the data link problem but was considered to be unacceptable to most potential users because of the necessity to support a staff of specially trained personnel to launch, operate, retrieve, and maintain the RPV. If the support of specially trained staff is not objectionable, the RPV approach to establishing the desired data link deserves strong consideration. According to the 1980 Booz-Allen report, RPVs suitable for this application can be expected to cost from $50K to $75K each.

It is known that forward scatter from ionized meteor trails can be used to communicate at distances beyond line-of-sight if frequencies in the range of 20 to 110 MHz are used [2]. Most ionization trails that are detected by radio waves are observed for only fractions of a second. These trails are produced by relatively small meteor particles which are in greater abundance than large meteor particles. (The mass distribution of sporadic meteors appears to be an approximately equal total mass of each size of particle). Larger meteors produce more densely ionized trails which have longer durations. Trails with durations of about 1 minute are observed several times per day; trails with durations of an hour or more are rare. The power returned to the receiver via forward scatter depends on factors such as the number of contributing meteor trails, the multipath phase relationship between multiple contributing trails, the orientation of the trail relative to the desired radio propagation path (the angle of incidence of the transmitted wave and the angle of reflectance to the earth based receiver should be equal relative to the surface normal of the meteor trail), and the polarization of the radio signal relative to the trail.

Meteor burst communications are normally conducted in the following way. To set up a link, an interrogating signal which sweeps over the known useful frequency band is radiated continuously until a strong return is observed at the opposite end of the link. The appropriate frequency is determined and, after appropriate end-to-end link coordination has been quickly established, communications (or data transfer) begins

and continues until the meteor path return fades out or the information transfer is complete. The communication process is, therefore, sporadic, but it may be very applicable to situations in which data can be collected, stored, and then transmitted in a high data rate burst when link conditions are favorable. According to the Booz-Allen report, excellent link power budget characteristics exist for this mode of communications for the ranges of interest. However, for applications in which continuous high data rate communications are required with high reliability, the meteor burst mode of communication will not be satisfactory.

The use of a satellite link is an attractive alternative to HF surface wave propagation in terms of RF power requirements, particularly during night time when the noise levels at the low frequency end of the HF band increase dramatically and cause diminished signal-to-noise ratios. Power requirements for data rates of 2,400 and 10,000 bps were calculated assuming a typical UHF geosynchronous satellite configuration with a hard-limiting transponder and 25 kHz channel bandwidth. Required carrier-to-noise ratio at the demodulator was calculated by the standard relation

$$CNR = E_b/N_0 + 10\ LOG\ (R) \qquad (1)$$

where R is the data rate and E_b/N_0 is the energy-per-bit to noise power density ratio corresponding to a given bit error rate for a given demodulator design. Our calculations assumed a DPSK demodulator with an E_b/N_0 requirement of 9.5 dB for a bit error rate of 10^{-3}. The buoy antenna was assumed to have a power gain of 0 dB relative to a circularly polarized isotropic antenna as was reported to be achievable in the Booz-Allen report. In addition to the free-space spreading loss, an additional 7 dB of anomalous loss was added to the up- and down-links to account for miscellaneous forms of absorption. A summary of parameter information assumed for the satellite, the up- and down-links, the source, and receiver are shown in Appendix A. For a 10,000 bps data rate, approximately 91 Watts (W) are required for the conditions stated. For a 2,400 bps rate, approximately 26.3 W are required. Reduction of the anomalous loss in the up-link will almost proportionally reduce the amount of RF power required at the buoy. Reduction of anomalous loss on the down-link has negligible effect since the noise and loss added by this link does not significantly effect the SNR established on the uplink.

The greatest difficulty with the satellite relay approach to solving the data/communications link problem is the availability of the satellite channel. Satellite channels are in short supply, and the exclusive use of such a channel for extended periods of time by an expendable buoy system is not realistic on a routine basis. Also, for missions with military significance, UHF satellite channels are easily jammed and easily listened to by unauthorized groups at large distances from the geographical region of the expendable buoy unless cryptographic encoding has been applied. There is probably no way to avoid the jamming threat except by using wider band satellite systems such as are being developed at EHF (Milstar), and at these frequencies the high gain antenna that would be required at the expendable buoy would present unacceptable beam-pointing problems. The use of cryptographic equipment at the buoy may also be an unacceptable encumberance. By contrast, the

HF surface wave method has a much smaller geographical area in which the radio signals are vulnerable to intercept; consequently, jamming is likely to occur only from sources that are within several hundred kilometers distance from the buoy.

Tropospheric scatter, which relies on reflections from random inhomogeneities and vertical gradients in refractive index, is most effective at ranges of about 1000 nautical miles and at frequencies in the UHF and VHF range. Link attenuation for a 200 nautical mile range would be near 200 dB for tropospheric scatter [1], while for HF surface wave propagation, link loss would be in the range of 110 to 150 dB [3]. Consequently, tropospheric scatter is not an effective means of establishing a data link for the system of present interest.

The principles of HF skywave are well understood and frequently discussed in many articles; consequently, we will assume the reader has a basic understanding in this area. Readers unfamiliar with HF propagation will find a good introduction in chapter 4 of Davies' book [2]. As with tropospheric scatter, HF skywave is a better propagation mode for larger separations between source and receiver than are of interest for the present application. Because of the natural characteristics of HF ionospheric refraction, most of the refracted radio wave power is returned to earth at ranges beyond 100 nautical miles. Hayden [4] has used ray tracing procedures to determine the approximate ground range that would be covered by a narrow beam of illumination (a ray) at source elevations ranging from 0 to 80 degrees relative to horizontal for frequencies throughout the HF range using ionospheric electron density profiles that are characteristic of diurnal, seasonal, and solar activity variations. Using Hayden's data it was determined that power arriving at a ground range of 185 km (100 n. miles) is attributable to source radiation at elevation angles between 45 and 75 degrees, depending upon the applicable ionospheric conditions. The power radiated within a fixed azimuthal swath by a quarter-wave (or shorter) monopole at these elevations is down by 5 and 18 dB, respectively, from that radiated at near-grazing elevation (surface wave direction). The elevation angles of rays that return to earth, via the skywave mode, at a ground range of 370 km (200 n. miles) span a range of approximately 25 to 65 degrees with losses in associated antenna directive gain of 1.5 to 12 dB for power radiated in a fixed azimuthal swath. The most favorable condition for obtaining skywave power in the 185 to 370 km range is a "daylight" ionosphere and low radio frequency. The general consensus is that at ranges less than approximately 185 km the HF skywave mode is useless, and at ranges between 185 and 370 km it may be an annoyance because of the occasional multipath interference it may cause with the surface wave component.

The remainder of this report will be devoted to analyzing the usefulness of HF surface wave propagation for supporting continuous communications over ranges of 185 to 370 km. Section II describes the analytical tools used to perform the power budget calculations. Section III discusses the results obtained, and the Summary and Conclusions are presented in Section IV.

II. Analysis Method

Calculations of link performance were conducted at frequencies of 3, 5, 7, and 10 MHz. In addition to falling at the lower end of the HF band where surface wave propagation is generally superior, these specific frequencies were chosen because at these values, Barrick [3,5,6] has estimated the propagation loss from various sea state conditions in addition to the smooth surface propagation loss for a spherical earth. Barrick's analysis of the effect of sea state is based on the use of two height-spectrum models for wind driven ocean waves: a directional Neumann-Pierson model and an isotropic Phillips model. Barrick provides three estimates of additional attenuation: one for the upwind-downwind condition (Neumann-Pierson), one for the crosswind condition (Neuman Pierson), and one for the isotropic (Phillips) condition. In our anlalysis, we have simply chosen the largest value in the set of three estimates. Care must be exercised in the use of Barrick's numerical results because they apply to antennas that radiate in free space, whereas our concern is with an antenna (such as a monopole) that radiates only in the half space above the ocean surface. Other workers [7] have noted that in this case 6 dB must be added to Barrick's results.

We have assumed, rather optimistically, that the ambient noise at the receiving site is determined entirely by atmospheric noise. Plausibly, this circumstance may be nearly achieved by a specially designed "quiet" ship or ocean platform or remote land-based site. In this regard, the prediction of source power requirements in this report must be considered to represent an optimistic or lower bound to the real world requirement. The noise-like degradation caused by other-user interference was also neglected. Other-user interference can be greatly reduced by using some form of spread spectrum modulation. For example, it is well known that if a spectrum spreading technique is used in transmission, proper despreading at the receiver can provide a margin against other-user interference (or jamming) equal to the ratio of the spread bandwidth to the actual information bandwidth. However, the use of wideband techniques with an intrinsically narrowband buoy antenna may produce diminishing returns because of the loss in antenna efficiency associated with the forcing of wider bandwidth. For data links employing spread spectrum techniques, the neglect of other-user interference may not be serious; however, for narrowband links the omission will be significant and estimates of other-user interference characteristic of that location must be inserted into the analysis.

Estimates of atmospheric noise were taken from CCIR report 322 [8]. Two extreme geographical locations were chosen to demonstate the effect of geographically dependent noise levels. The location of the Bering Strait (65 degrees north latitude, 168 degrees west longitude) was chosen to characterize noise levels at high latitude sites and the location of Cuba (22 degrees north latitude, 80 degrees west longitude) was chosen for low latitudes. Noise estimates were extracted from the CCIR report for each frequency analyzed during each four-hour diurnal time increment and for each of the four seasons of the year. For each four-hour time block, the highest and lowest noise estimates (corresponding to the seasonal variations) were used for calculations of the two extremes in propagation performance. Since noise is a fluctuating quantity, a statistical estimate of reliability should accompany the noise estimate. In this report

we have chosen to work at a 90% confidence level, which implies that the noise estimate used is exceeded only 10% of the time. Ninety percent confidence noise estimates were obtained by adding to the mean hourly values of atmosperic noise (F_{am}) the upper decile values which are also provided in the CCIR 322 report.

The next issue of importance is a discussion of the method used to predict the performance of the buoy antenna. The approach taken was to keep the analytic method as simple as possible while still reflecting the basic characteristics of the antenna and matching network such as bandwidth, loss, impedance, and power transfer. The basic model used to analyze the antenna (in the radiation mode) is shown in Fig. 1.

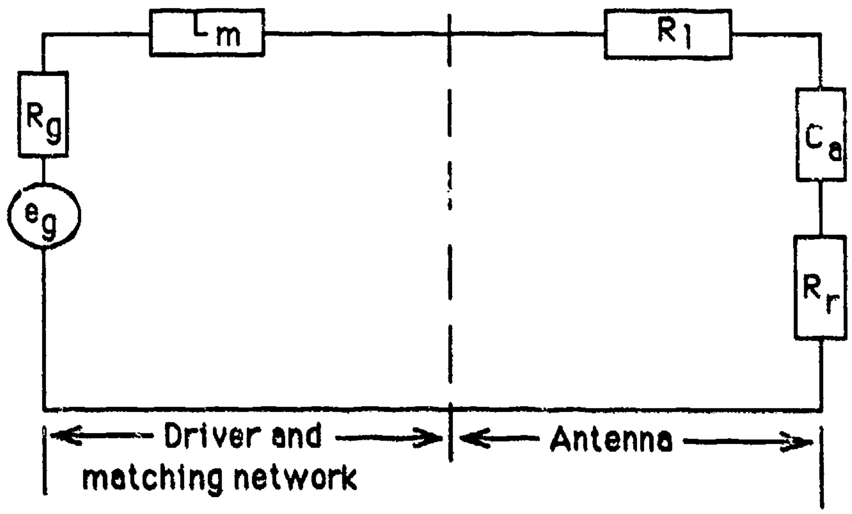


Fig. 1. Equivalent circuit of antenna, driver, and matching network.

In Fig. 1 we identify the symbols as:

- R_r = radiation resistance of the antenna
- C_a = capacitance of the antenna (antenna is electrically short)
- R_l = loss resistance
- L_m = inductance of matching metwork
- R_g = resistance of driver (generator)
- e_g = driver (generator) voltage

For simplicity we assume that the antenna is electrically short (less than quarter-wavelength for a monopole) so that its impedance can be modeled as a resistor and capacitor in series. The function of the matching inductor L_m is to cancel the capacitive reactance of the antenna ($-1/(wC_a)$) at a specific frequency, usually at the center of the operating band. Here, $w = 2\pi f$ where "f" denotes frequency. The impedance of the driver is assumed to be purely resistive and of value R_g. The loss in the transfer of power from the driver to the antenna caused by impedance mismatch is given by [9]

$$\pounds = [(R_r + R_g + R_l)^2 + (wL_m - (wC_a)^{-1})^2]/(4R_gR_r) \tag{2}$$

We note that, as required, the loss predicted by (2) is unity when the loss resistance is zero, the resistance of the generator equals the radiation resistance of the antenna, and the reactances cancel. The loss calculated by (2) does not include an additional source of loss caused by standing waves on a length of transmission line that may be used to interconnect the antenna and driver. If the length, characteristic impedance, and loss at unity standing wave ratio (SWR) are known for the transmission line, the additional loss from a higher SWR can be estimated from equations given in [9].

When the radiation resistance of the antenna differs significantly from that of the driver, an impedance transforming device is usually inserted into the matching network to reduce the matching loss £. We will assume that an ideal impedance transforming device follows the driver and results in a change in driver resistance from R_g to R_g/N^2, where

$$N = [R_g/(R_r + R_l)]^{1/2} \tag{3}$$

With this addition to the equivalent circuit, (2) transforms to

$$\pounds = [(R_r + R_l + R_g/N^2) + (wL_m - (wC_a)^{-1})^2]/(4R_rR_g/N^2) \tag{4}$$

We cannot assume that the buoy antenna will always have sufficient bandwidth to support the desired mode of communications, particularly if wideband methods of modulation are used. Bandwidth can usually be increased with the sacrifice of efficiency by adding additional loss resistance to the antenna. Consequently, we will now extend the concept of matching loss to include the effect of a minimum required bandwidth. The fractional efficiency (E) of the antenna and matching network for a given RF bandwidth is equal to the ratio of £ at the band edge to £ at the center frequency.

$$E = \pounds(\text{band edge})/\pounds(\text{band center}) \tag{5}$$

Assuming optimal impedance transformation as given by (3), equation (5) reduces to

$$E = [(R_r + R_l)^2 + K^2]/(R_r + R_l)^2 \tag{6}$$

where $$K^2 = (1/4)[wL_m - (wC_a)^{-1}]^2. \tag{7}$$

If we let $f = f_0$ and $K = 0$ at the center of the RF band and $f = f_0 + BW/2$ at the band edge (where BW = RF bandwidth), then the expression for K can be re-cast in the form

$$K = [\pi L_m(BW)/2][1 + 4f_0/(BW)]/[1 + 2f_0/(BW)] \tag{8}$$

Inserting (8) into (6) and rearranging to solve for the minimum required R_l for a given efficiency, radiation resistance, and bandwidth, we have

$$R_l = |K|[E-1]^{-1/2} - R_r \tag{9}$$

where | | denotes absolute value.

In the computations of antenna performance associated with this report, the following procedure was used to compute antenna/matching-network loss for a given required bandwidth at a specific operational frequency. The radiation resistance and capacitance were calculated for the antenna at the desired center frequency (the method used to accomplish this will be discussed subsequently). The inductance required to cancel the reactance of the antenna was determined and then |K| was calculated via (8). The value of E is just the ratio of the loss at band edge to the loss at band center that is acceptable, say 0.63 (-2 dB) for example. This information was used with (9) to determine the minimum loss resistance required to achieve the required bandwidth. Equation (4) is then used to calculate the matching loss at center frequency and/or at band edge.

The impedance of the buoy antenna was calculated assuming that the antenna was a monopole of height H and uniform thickness (diameter) of 2a. For this case the antenna reactance is given by [10]

$$X = -15\Big\{\sin(2\beta H)\Big[-.5772 + \ln(H/\beta a^2) + 2\,\mathrm{Ci}(2\beta H) - \mathrm{Ci}(4\beta H)\Big] - \cos(2\beta H)\Big[2\mathrm{Si}(2\beta H) - \mathrm{Si}(4\beta H)\Big] - 2\mathrm{Si}(2\beta H)\Big\}/\sin^2(\beta H) \tag{10}$$

where $\beta = 2\pi$/(wavelength) and Ci and Si are the cosine and sine integrals [11]. When the reactance is capacitive (i.e. sign(X) < 0), the capacitance of the antenna is given by

$$C_a = \left[2\pi f|X|\right]^{-1} \tag{11}$$

A computer program was written to determine C_a using (10) and (11). Polynomial approximations for Ci and Si were obtained from equations 5.2.14 and 5.2.16 of [11]

for argument < 1, and equations 5.2.8, 5.2.9, 5.2.38, and 5.2.39 of [11] for argument >= 1.

The radiation resistance of a monopole antenna is primarily a function of the ratio of height to wavelength. This relationship is shown graphically in figure 14-7 of [10] and was found to fit the expression

$$R_r = 400(H/\text{wavelength})^2 + 3700(H/\text{wavelength})^4 \qquad (12)$$

with sufficient accuracy for the purpose at hand for (H/wavelength) < 0.3. Equation (12) can be recast in terms of frequency by the relation f x (wavelength) = 3×10^8 meters/sec.

Having discussed all of the individual steps required for the analysis of HF surface wave propagation from an expendable buoy with a monopole antenna, we are left with the final step of calculating the signal-to-noise ratio (SNR). Following standard procedure, we calculate the power level of the received signal (S) as a product of the transmitted power, the transmitter and receiver gains, and the reciprocals of the losses

$$S = P_t G_t G_r / (£_t £_p £_r) \qquad (13)$$

where P_t is the "available power" (i.e. the power provided to the antenna and matching network combination), G_t and G_r are the directive gains of the transmitter and receiver, $£_t$ is the power loss in the transmitting antenna and matching network (equation(4)), $£_p$ is the surface wave propagation loss obtained from Barrick [3,6], and $£_r$ is the loss in the receiving system (to which we have attributed 2 dB from the matching network and 1 dB from the transmission line).

The total system noise is simply the product of the effective noise factor (f_e) times the thermal noise kT_0B, where B is the noise bandwidth which we assume to be twice the data rate. The effective noise factor is determined by noise contributions outside the receiver, noise sources within the receiver, and losses and noise sources within the transmission line and matching network. This relationship is expressed mathematically as [8]

$$f_e = f_a - 1 + f_m f_T f_r \qquad (14)$$

where f_a is the atmospheric or ambient noise factor (noise relative to kT_0 as observed on a noiseless receiving system), f_r is the noise factor of the receiver (we have assumed $f_r = 2$ (3 dB) in the calculations), f_T is the noise factor of the transmission line leading to the receiver (this is usually equated to its loss which we have assumed to be 1.26 (1 dB)), and f_m is the noise factor associated with the matching network of the receiving antenna (usually equated to its loss which we assumed to be 1.58 (2 dB)).

The SNR is then

$$SNR = P_t G_t G_r / \left[\ell_t \ell_p \ell_r k T_0 B (f_a - 1 + f_m f_T f_r) \right] \tag{15}$$

The amount of SNR required to support communications with an acceptable error rate is dependent upon the demodulator design. We have assumed for purposes of calculation that an SNR equal to or greater than 20(13 dB) is required. Having fixed the SNR at a minimum of 13 dB, one can calculate either the amount of driver power required to sustain a specified data rate at a given range, RF bandwidth, frequency, and noise circumstance (such as time of day, geographical location,season) or, alternatively, the data rate that can be sustained by a fixed amount of available driver power. The specification of RF bandwidth is important to account for reduced antenna efficiency (via equations (8, 9, and 4)) when spread spectrum modulation is used and demands instantaneous RF bandwidths considerably larger than the information bandwidth. The computer algorithm written (in BASIC) to perform the calculation of SNR as well as the preliminary steps of calculating antenna impedance, radiation resistance, amount of loss resistance required to provide a nearly flat specified RF bandwidth (within 2 dB), and matching loss to the transmitting buoy antenna is shown in Appendix B. Presentation of this computer program is primarily for the sake of completeness in the understanding of the abilities and limitations of the analysis method. No attempt was made to optimize the appearance or "readability" of the coding for the convenience of other potential users.

In addition to the limiting assumptions already discussed relative to the use of equation (15), additional discussion is necessary concerning the effect of sea state on the ability of the matching network to provide efficient power transfer to the buoy antenna. The problem may be visualized as described in the following narrative. Assume that the sea is perfectly calm and the matching network has done a perfect job of canceling the reactance of the antenna. Now assume that waves have developed on the sea surface. Although the buoy follows closely the vertical motion of the waves, the antenna does not quite retain the same relative height in the water that it did with no wave action (e.g. the buoy "bobs" slightly). The ability to retain precise positioning of the base of the antenna relative to the local ocean surface diminishes as the sea state grows.

There are primarily two effects on the antenna that must be considered. The first consideration is antenna wetting. If an insulating or dielectric coating is not provided over the lower portion of the antenna, wave slosh will cause antenna wetting and electrical shorting which will render the antenna useless until the conductive film (seawater) has vanished. Proper antenna design is feasible to eliminate the direct shorting problem. The second effect to be considered is the change in antenna impedance caused by a bobbing antenna. As discussed previously, at the lower end of the HF band where surface wave propagation is likely to be employed, the buoy antenna will be electrically short and will, therefore, exhibit a large reactance and a relatively small radiation resistance. The ability to couple power efficiently to this antenna depends upon this reactance being canceled by a compensating element in

the matching network. Unless the matching network can adaptively adjust the reactance canceling element (in response to a measure of impedance mismatch such as standing-wave ratio or reflected power) and accomplish this adjustment in a time interval much less than the shortest significant wave period, the effective matching loss may be significantly greater than that calculated by equation (4). The use of adaptive impedance matching networks in expendable buoys will add significant complexity to the hardware and may be financially unattractive.

It is important to estimate the magnitude of increase in matching loss caused by antenna bobbing with a nonadaptive matching network. A rigorous analysis of this effect would be extremely complex; consequently, we have instituted simplifying assumptions that facilitate the estimation of a lower bound to this effect. We model the situation by assuming that the bobbing of the antenna is equivalent to a lengthening or shortening of the antenna after the matching network has been optimized appropriately for an initial height of the antenna relative to the surface. This situation can be realized approximately in a real system by adding a dielectric jacket to the monopole antenna in a way that looks like an extention of the dielectric jacket in the feeder transmission line. An increase in the height of the ocean surface, which forms the ground plane, appears as an extention of the transmission line and a reduction in the length of the antenna. With proper attention to relative dimensions of the antenna and jacket thicknesses, the characteristic impedance of the transmission line can, in principle, be maintained in the washover region. However, as the diameter of the antenna is increased near the base area (to increase bandwidth and reduce ohmic losses), the practicality of applying a dielectric jacket of sufficient width to preserve the characteristic impedance of the transmission line diminishes. In the next section of the report the effect of antenna bobbing is presented graphically as the result of a shortening of the length of a monopole antenna following establishment of fixed impedance matching conditions at the original antenna length. The results are shown for several frequencies and for several fixed impedance transformation ratios.

III. RESULTS AND DISCUSSION

The computational method which was described in the previous section and is listed as BASIC code in Appendix B was used to analyze the HF surface wave propagation performance for two antennas, each having a length (height) of 5 meters but different thicknesses (.20 and .0254 meters). The thicker antenna appears to offer slightly better performance at lower frequency and is presently of greater interest for implementation with experimental systems; consequently, most of the emphasis will be on results obtained with this antenna. Data will also be presented for the thinner antenna, but a detailed discussion of these results will not be given. Interpretation of the results for the thinner antenna will present little difficulty after following the discussion provided for the thicker antenna.

For proper interpretation of the data, the following properties should be remembered. Atmospheric noise increases during the night time hours, particularly at low frequencies, because of the absense of the D-layer which acts as an absorbing medium during daylight hours when the presence of the layer is fully developed.

Operational areas which are far away from the major source of noise (equatorial thunderstorms) experience lower noise than closer ones because of the cumulative effect of a longer propagation path through the absorbing medium. Consequently, during night time hours, the difference in noise levels between a low latitude area and a high latitude area may be less than during the day time. Atmospheric noise is also dependent on frequency and, in general, tends to increase with decreasing frequency. For high noise areas the noise increases monotonically with decreasing frequency, but at lower noise areas the noise vs frequency curve frequently has a minimum [8] in the lower end of the HF band which can lead to lower noise at 2 to 3 MHz than at 10 MHz. The extremes between seasonal noise levels is dependent upon geographical location. For the two locations studied in this report, the difference between seasonal noise extremes was smaller at the higher latitude of Bering Strait than at the lower latitude area of Cuba. A final point for consideration is that the extremes in diurnal variation of noise decrease as the frequency increases.

Basic surface wave propagation loss (for a smooth surface) increases with frequency, and the additional loss contributed by surface roughness (as specified by a given sea state) increases dramatically with frequency. Consequently, from the standpoint of propagation conditions alone, it is best to remain at low frequencies in the HF band (probably at or below 3 to 5 MHz). From the viewpoint of the buoy antenna, which is electrically short at low HF frequencies, power transfer from the driver to the antenna is less efficient at low frequencies, particularly when large RF bandwidths are required to support wideband modulation schemes.

The choice of an optimum frequency for an expendable buoy system, therefore, depends upon the frequency dependence of (a) the efficiency-bandwidth product of the antenna, (b) the noise, (c) the propagation loss, and (d) the additional loss caused by seastate. Because of the interaction of all these effects, it is difficult to predict a priori the frequency that is best suited to a particular range, time of day, and sea state condition. Hence we resort to computer modeling/simulation to provide guidance.

In the computational examples that will be presented, we will use the locations of the Bering Strait and Cuba to demonstrate the effect of geographical variablity of atmospheric noise. The antenna dimensions will be held constant at 5 meters length and 0.2 meters thickness for the first set of examples. Nearly optimum impedance matching will be assumed for the transmitting antenna. The "nearly optimum" qualification means specifically that the resistance in the antenna and matching network is at least one ohm but otherwise not greater than that required to maintain the required RF bandwidth (equation (9)), the reactance of the antenna is exactly canceled at mid band, and the impedance transformation ratio is adjusted optimally within a 10:1 or 1:10 ratio. If the optimum ratio is outside this range, it is, nevertheless, held to the indicated range.

Thick Antenna, 100 kHz RF Bandwidth

The first example we consider is for the Cuba location (high noise area). We consider a range of 278 km (150 N. mile), a data rate of 2400 bits/sec, and an RF bandwidth of 100 kHz. We assume the large RF bandwidth is required for wideband

modulation techniques used to reduce interference from other user noise. Calculations are presented for frequencies of 3, 5, 7, and 10 MHz and for sea states of 0, 2, 4, and 6. In some cases (primarily at 3 MHz) where the data for high sea states differ little from that of sea state 0, the results are not presented. The driver power required to support the 2400 bit/sec data rate at an SNR of 13 dB is plotted as a function of time of day. The temporal nature of the data is based on the diurnal estimates of atmospheric noise obtained from [8]. These estimates are given in six groups of four-hour blocks. For plotting purposes the time of day was set at the center of each four block. Because of inherent limitations of the plotting package used, the time axis of the data plot spans 2 to 22 hours instead of the desired 0 to 24 hours. The results for the first example are shown in the figures of appendix C.

Figure C-1 is a summary of the values used for surface wave propagation loss for this range at each frequency and for sea states 0 (basic loss), 2, 4, and 6. Figure C-2 shows the predicted diurnal variation in required driver power at a frequency of 3 MHz and for sea state 0. Two sets of points are presented, one corresponding to the seasonal high estimate of atmospheric noise ("worst case"), the other corresponding to the seasonal low estimate ("best case"). The data below the plot show the actual atmospheric (or environmental) noise figure used for each four-hour time block. The plot provides a dramatic illustration of the wide variation (three decades in this instance) in atmospheric noise throughout a 24 hour period. For lowest seasonal noise, there are two time blocks for which communications are possible (within the previously stated assumptions of this analysis) with less than one watt of power and three time blocks for which more than 100 watts are required. For the case of highest seasonal noise there is only one time block for which communications are possible with ten watts or less and four blocks for which 1000 watts or greater are required. Figure C-3 shows that at the frequency of 3 MHz the effect of surface roughness up through sea state 6 has negligible effect on communication performance.

Figures C-4, 5, and 6 show the data for a frequency of 5 MHz at sea state 0, 4, and 6. Only at sea state 6 is there an appreciable change in the data. Performance is somewhat better at this frequency than at 3 MHz. For lowest noise conditions, communications would be possible over a 24 hour period with 90% confidence with a maximum driver power of 30 to 40 watts. For highest noise conditions, however, the maximum driver power required to support 24 hour continuous communications would approach 1 kilowatt.

Figures C-7, 8, and 9 show the data at 7 MHz for sea states 0, 4, and 6. At sea state 0, performance continues to improve over that at 3 and 5 MHz. Now, even with conditions of highest seasonal noise, communications are possible for the entire 24 hour period with a maximum driver power of about 300 watts. However, at sea states near 4 and above the advantage of the higher operating frequency is lost.

Figures C-10, 11, 12, and 13 show the data for a frequency of 10 MHz at sea states of 0, 2, 4, and 6. At sea state 0, the results are nearly comparable to those at 7 MHz except that somewhat more power is required during the mid day period (i. e. the curves are flattening out). At 10 MHz the effect of surface roughness is evident at sea

state 2 but not severe until sea state 4. The effect of sea state 6 is devastating -- requiring many kilowatts of power for 5 out of six time blocks for the highest noise condition. Apparently, for the present set of circumstances, a frequency near 7 MHz is optimal if sea state conditions are low to moderate. For high sea state conditions, a frequency of 5 MHz would be better.

We now focus our attention on the geographical location of the Bering Strait and observe the power requirements associated with communicating to a range of 278 km in this quieter region. The data for this region, with all other parameters the same as previously established, are shown in Appendix D. Figure D-2 shows the power required at 3 MHz and sea state 0. As before, the effect of sea states through 6 was negligible at this frequency; consequently, the data are shown for sea state 0 only. With the lower noise levels characteristic of this geographical area, communications are theoretically possible over the 24 hour period with a maximum power of about 20 watts.

Figures D-3, 4, and 5 show the power requirements at a frequency of 5 MHz and sea states 0, 4, and 6. At a sea state of 4 or less, an operational frequency of 5 MHz appears to be a better choice than 3 MHz; however the advantage is lost at sea state 6.

Figures D-6, 7, and 8 show the power requirements at 7 MHz for sea states 0, 4, and 6. Even at sea state 0, an operational frequency of 7 MHz appears to be inferior to the previous choice of 5 MHz. We note that at 7 MHz the advantage of lower environmental noise is negated by the larger propagation loss (reference: figures C-2 and D-3).

Figures D-9, 10, 11, and 12 show the power required at 10 MHz and sea states 0, 2, 4, and 6. At all sea states, more power is required at 10 MHz than at 7 MHz; consequently, we conclude that frequencies above 7 MHz are probably not a good choice for this application. Again, the diurnal variation of the data is much smaller at the higher frequencies because of the smaller spread in values of atmospheric noise throughout the 24 hour period.

The amount of driver power required for a range of 370 km (200 n. mile) is shown in the figures of Appendix E for each of the two sites at frequencies of 3 and 5 MHz at sea state 0 only. Theso data differ from the previous examples at a range of 278 km only by the additional propagation loss which is 7 dB at both frequencies.

The figures of Appendix F show the power required at a range of 185 km (100 n. mile) for the two sites at frequencies of 3 and 5 MHz and at sea state 0. Again the diurnal variation is identical to that at 278 km range except that the power required at 3 MHz is 6 dB less at 185 km range and is 9 dB less at 5 MHz.

Thick Antenna, 10 kHz RF Bandwidth

Calculations identical to those just presented were performed for the same antenna but with the RF bandwidth requirement reduced from 100 kHz to 10 kHz. The only difference in the results is in the difference in the matching loss to the transmitting antenna. The difference is 8.7 dB (12.8 - 4.1) at 3 MHz, 1.4 dB (2.7 - 1.3) at 5 MHz, and of negligible amount at 7 MHz and above. The impact of this reduction in matching loss is the achievement of approximately comparable power requirements at 3 and 5 MHz for the case of 10 kHz RF bandwidth. This result may be misleading in that the reduction in RF bandwidth precludes the use of spectrum spreading techniques to reduce the effect of other-user interference. Other-user interference may negate any gains achieved by the reduced RF bandwidth.

Effect of Antenna Bobbing (Thick Antenna)

Appendix G shows the variation in matching loss as the antenna is effectively shortened by a wave swell or surge which the buoy has not followed precisely. The method and simplifying assumptions used to make these calculations were discussed in the previous section. We repeat here that the antenna was tuned for "normal" position in the water (i.e. at an antenna length of 5 meters) by canceling reactance, adding, if necessary, sufficient resistance to obtain the required bandwidth, and then selecting a transformer ratio; these conditions were then frozen while the antenna length was effectively changed by wave action. Figures G-2 to G-5 show the matching loss as a function of change (decrease) in antenna height for the case of 100 kHz RF bandwidth and frequencies of 3, 5, 7, and 10 MHz. The effect of fixed transformer ratios of 0.3:1, 1:1, 3:1, and 10:1 are shown; a 10:1 ratio implies a step-down of the driver impedance by a factor of 10. At 3 MHz and for washover heights up to 0.4 meters height, a transformer ratio in the range of 1:1 to 3:1 is near optimum. For the 3:1 ratio, which is optimum for the calm sea condition (no washover), an additional 6 dB of loss occurs for 0.4 meter washover height. Approximately 1.4 dB less loss occurs at 0.4 meter height for a ratio of 1:1; however, the 1:1 ratio results in about 3 dB more loss at zero washover height. Actually, the results at 3 MHz are less sensitive to washover than at 5 and 7 MHz because so much loss has been introduced to the antenna to achieve the 100 kHz bandwidth at 3 MHz that the variation in reactance, induced by the change in effective height, is less significant than at the higher frequencies where the 100 kHz bandwidth can be achieved with less loss.

Figure G-3 shows the variation in matching loss at 5 MHz frequency. Here we see that the optimum transformer ratio at zero washover height (the ratio always used in the previous calculations for required driver power) of 10:1 exhibits a 15 dB increase in loss at a washover height of 0.4 meter. A significant improvement can be achieved in reduction of matching loss at 0.4 meter washover height by using a 3:1 or 1:1 transformer ratio, albeit at comparable increase in loss at zero washover height. The situation changes only slightly at 7 MHz. At 10 MHz the antenna is approximately 0.17 wavelengths long, and the reactance is becoming less significant in comparison to the radiation resistance; consequenty, moderate changes in effective length at fixed matching conditions have smaller impact. For this frequency, Fig. G-5 shows that a 3:1 ratio is optimum up to about 0.7 meter washover height, and the additional loss introduced at a washover height of 0.4 meter is only about 1.2 dB.

Figure G-6 shows the washover effect for a 10 kHz bandwidth at a frequency of 3 MHz. This example shows more sensitivity to washover than was evident for the 100 kHz bandwidth case because the narrower bandwidth allowed the use of less loss resistance. At frequencies of 5 MHz and higher, there is little loss penalty with this antenna for using 100 kHz bandwidth instead of10 kHz bandwidth; consequently, the washover effect is almost identical to that shown in Figs. G-3, 4, and 5 for either choice of RF bandwidth.

Thin Antenna

Power requirements to sustain a data rate of 2400 bits/sec at a ranges of 185 to 370 km (100 to 200 n. miles) were also investigated for an antenna having the same 5 meter length but a thickness of only .0254 meter. Basically, the only difference between the two antennas is that the thicker antenna will provide a better efficiency-bandwidth product at lower frequencies. Results presented for the thicker antenna for a given RF bandwidth can be applied to the thin antenna for any specified bandwidth if the difference in matching loss is known. Consequently, we have documented in Table 1 the matching loss for the 0.2 and 0.0254 meter thickness antennas for RF bandwidths of 10, 25, and 100 kHz at frequencies of 3, 5, and 7 MHz. At 10 MHz and beyond, our model predicts only the 0.66 dB loss associated with one ohm of loss resistance.

Table 1: Matching loss (in dB) associated with a 5 meter length monopole antenna as a function of RF bandwidth and frequency.

	0.2 meter antenna thickness			.0254 meter antenna thickness		
BW >>>	10 kHz	25 kHz	100 kHz	10 kHz	25 kHz	100 kHz
FREQ						
3	4.13	6.38	12.86	4.69	9.07	15.1
5	1.34	1.43	2.79	1.38	1.65	5.42
7	0.66	0.66	0.77	0.66	0.68	1.03

From the data of Table 1 it is evident that (a) for 10 kHz RF bandwidth there is very little advantage gained by the use of the thicker antenna, (b) for 25 kHz bandwidth there is approximately 2.7 dB advantage to using the thicker antenna at 3 MHz, but little advantage at 5 MHz and above, and (c) for 100 kHz bandwidth there is somewhat in excess of 2 dB advantage to using the thicker antenna at frequencies up to 5 MHz. This statement must be qualified by the assertion that our calculations account for the reactance and radiation resistance of the monopole antenna but do not attempt to compute actual loss resistance (other than what is required to produce a given bandwidth) which depends upon ground plane characteristics as well as antenna features. We assume that the .0254 meter thickness antenna is capable of achieving

low resistive loss when this condition is compatible with the bandwidth requirement. We stress that low loss is not always compatible with the demand for bandwidth; using the 0.2 meter thick antenna, it is necessary to add 11 ohms resistance to achieve a bandwidth of 100 kHz.

Effect of Antenna Bobbing (Thin Antenna)

The approximate variation of matching loss with change in antenna height (caused by wave action) for the thin antenna is shown in Appendix H. Figures H-2, 3, 4, and 5 show the variations for 100 kHz bandwidth at frequencies of 3, 5, 7, and 10 MHz. Figures H-6 through 9 show the variation for 10 kHz RF bandwidth. In most cases the slope of the loss versus the change in antenna height is initially steeper than those corresponding to the thicker antenna (Appendix G).

IV. Summary and Conclusions

The use of the HF surface wave propagation mode has been examined for maintaining a continuous data link to ranges of 185 to 370 km (100 to 200 n. miles) from an expendable, ocean deployed buoy. We have assumed that the maximum size antenna that can be used with the buoy while preserving dynamic stability is a monopole of 5 meters length and 0.2 meters thickness. A mathematical method was developed to calculate the required driver power to sustain a specified data rate over a given propagation range at a specified frequency. The propagation loss was estimated from Barrick's report [3,6] as a function of range, frequency, and sea state. The ambient noise level at the receiving site was assumed to be predominantly atmospheric noise as predicted by CCIR report 322 [8] as a function of geographic position, frequency, time of day, and season of the year. Additional sources of artificial or man-made noise, generally refered to as "other-user noise", is assumed to have been reduced to a negligible level by spread spectrum or frequency hopping techniques. We assume that there is no implementation loss for the spread spectrum modulation/demodulation processes. Losses in the impedance matching network between the buoy power amplifier (driver) and the transmitting antenna were calculated by using a simple but realistic equivalent circuit model. The relationship between desired antenna RF bandwidth and corresponding efficiency was reflected in the calculations.

The computation of required driver power as a function of range, frequency, sea state, and geographical location using the scheme outlined above must be regarded as an optimistic estimate and/or a lower bound to the actual requirement in a real ocean environment. Not included directly in the calculations is the effect of additional, time varying losses in antenna efficiency caused by the antenna bobbing in the water (changes in electrical feedpoint height) and wave splash. The effect of antenna bobbing was modeled using the simplifying assumption that changes in feedpoint height could be treated as a lengthening or shortening of the antenna with a fixed matching network(justification for this approach is given in the Section II of the report). The additional antenna loss associated with a given change in feedpoint height was equated to the additional matching loss caused by an equivalent change in length of the antenna. The additional loss was computed assuming that the matching network

was optimized at the nominal deployment height of the antenna and that the matching was held constant as the antenna bobbed in the water. Calculations were performed at several values of impedance transformation ratio in order to demonstrate the sensitivity to this parameter. Values of additional loss computed by this method should also be considered to be a lower bound to the actual additional loss caused by antenna bobbing in the real ocean environment.

The majority of the computations were conducted for a range of 278 km (150 n. miles) and for geographical locations of Cuba (low latitude, high noise example) and the Bering Strait (high latitude, low noise example). Supplemental calculations were also conducted for ranges of 185 km (100 n. miles) and 370 km (200 n. miles), but with less completeness (the effect of varying sea states was not included for these ranges and frequencies were limited to 3 and 5 MHz).

The results of the calculations of required driver power for a range of 278 km are summarized in Table 2 for the relatively high noise Cuba location and in Table 3 for the relatively quiet Bering Strait location. The diurnal variation of the atmospheric noise is presented by the CCIR 322 report as noise values for each of six four-hour time blocks spanning the complete day. The driver power requirement for each time period is different; consequently, in Tables 2 and 3 we show the power required (for conditions of (seasonal low)/(seasonal high) noise) to satisfy (a) all six time blocks, (b) five out of six time blocks, and (c) four out of six time blocks. The noise estimates used are based on 90 percent confidence (exceeded only 10 percent of the time).

Table 2: Summary of driver power (in watts) required for communications over a range of 278 km near the geographical location of Cuba. Values are for seasonal low/seasonal high noise estimates. (SS = sea state).

FREQ	SS	6/6 time blocks	5/6 time blocks	4/6 time blocks
3	0-6	199/7560	151/2450	129/2040
5	0	31.5/1200	31.5/435	19.9/190
5	4	38.8/1470	38.8/535	24.5/234
5	6	128/4880	128/1770	81.0/773
7	0	28.6/273	19.3/207	14.0/137
7	4	67.0/640	45.3/486	32.8/321
7	6	509/4860	344/3680	249/2430
10	0	54.9/436	38.9/257	32.3/229
10	4	398/3160	282/1860	234/1660

Table 3: Summary of driver power (in watts) required for communications over a range of 278 km near the geographical location of Bering Strait. Values are for seasonal low/seasonal high noise estimates. (SS = sea state).

FREQ	SS	6/6 time blocks	5/6 time blocks	4/6 time blocks
3	0-6	9.1/18.2	7.7/15.1	0.19/10.0
5	0	3.7/5.47	3.2/4.77	0.35/3.22
5	4	4.55/6.74	3.88/5.87	0.42/3.97
5	6	15.1/22.3	12.8/19.4	1.40/13.1
7	0	3.86/5.98	2.27/5.09	1.37/4.53
7	4	9.04/14.0	5.33/11.9	3.21/10.6
7	6	68.6/106	40.4/90.4	24.4/80.6
10	0	10.5/26.9	4.9/14.8	3.8/14.8
10	4	75.8/195	35.5/107	27.5/105
10	6	208.8/537	97.7/295	75.9/288

Table 4: Summary of driver power (in watts) required for communications over a range of 370 km near the geographical location of Cuba. Values are for seasonal low/seasonal high noise estimates. (SS = sea state).

FREQ	SS	6/6 time blocks	5/6 time blocks	4/6 time blocks
3	0	997/37,900	757/12,300	644/10,200
5	0	158/6000	158/2180	99.6/951

Table 5: Summary of driver power (in watts) required for communications over a range of 370 km near the geographical location of the Bering Strait. Values are for seasonal low/seasonal high noise estimates. (SS = sea state).

FREQ	SS	6/6 time blocks	5/6 time blocks	4/6 time blocks
3	0	45.6/91.0	38.8/75.5	0.95/50.0
5	0	18.6/27.4	15.8/23.9	1.73/16.2

Table 6: Summary of driver power (in watts) required for communications over a range of 185 km near the geographical location of Cuba. Values are for seasonal low/seasonal high noise estimates. (SS = sea state).

FREQ	SS	6/6 time blocks	5/6 time blocks	4/6 time blocks
3	0	50.0/1900	37.9/615	32.2/512
5	0	3.97/151	3.97/54.7	2.50/23.9

Table 7: Summary of driver power (in watts) required for communications over a range of 185 km near the geographical location of the Bering Strait. Values are for seasonal low/seasonal high noise estimates. (SS = sea state).

FREQ	SS	6/6 time blocks	5/6 time blocks	4/6 time blocks
3	0	2.29/4.56	1.95/3.79	.048/2.51
5	0	0.47/0.69	0.40/0.60	.044/0.41

From these tables we can make the following observations. For a range near 278 km and for a very calm sea state, the optimum operational frequency is near 7 MHz for the low latitude location and closer to 5 MHz for the high latitude site. At sea state 4 , the better choice of operational frequency is 5 MHz. At sea state 6, 3 MHz becomes a better operational frequency at high latitude while 5 MHz appears slightly superior at low latitude.

For a range of 278 km in a high noise geographical area such as Cuba, the minimum driver power required to continuously support a data rate of 2400 bits/sec ranges from 28 to 273 watts, depending upon the season of the year, for a perfectly calm sea. If the requirement for communications can be dropped during the night time hours, when noise levels increase, significantly less power is required as was demonstrated in the figures of Appendix C. For a moderate sea state condition (sea state 4), driver power ranges from 38 to 1470 watts depending upon the season of the year. Even after excluding the two noisiest 4-hour segments of the day, driver power ranging from 24 to 234 watts is required.

For the same range but at a quieter location such as the Bering Strait, the required driver power ranges from 3.7 to 5.5 watts at sea state 0. Even at sea state 6, a driver power of 22 watts would be adequate at frequencies of 3 and 5 MHz for the entire 24 hour time period.

For a range of 370 km, the required driver power is unrealistically large for an expendable buoy system in the high noise location even at sea state 0. For the low

noise location, continuous communications appear to be feasible at this range since a power level of less than 30 watts is still adequate at sea state 0.

At a range of 185 km, communications are probably feasible most of the time at almost all geographical areas; however, power levels near 150 watts may be required during a few hours of the night during the noisiest season of the year.

To the power requirements summarized in Tables 2 through 7 should be added an additional margin for loss in efficiency caused by the antenna bobbing in the water. Based upon the simplified (and overly optimistic) assessment of additional loss caused by this effect (Appendix G), an additional power margin of at least 6 dB would be reasonable for moderate sea states. This additional factor applies for antennas that are well designed against the effects of antenna wetting caused by wave washover. The additional 6 dB of power required to compensate for the antenna bobbing problem casts a cloud of gloom on the usefulness of the HF surface wave method for supporting the desired data link for moderate to high sea state conditions. The additional 6 dB of power budget margin can also be gained by reducing the data rate by a factor or four to 600 bits/sec; however, this reduction may be unacceptable for many applications.

A few dB of improvement can be achieved by the use of a highly efficient receiving system. We have assumed a 3 dB power loss in this system, 1 dB in the transmission line and 2 dB in the matching network. Also, the use of a receiving antenna with directional gain greater than that of a monopole will reduce the power required for the buoy antenna driver.

The use of a narrower, 10 kHz RF bandwidth, to allow higher antenna efficiency reduces the driver power requirement by 8.7 dB at 3 MHz, 1.4 dB at 5 MHz, and by a negligible amount at 7 MHz and above. However, the use of a narrower RF bandwidth precludes the use of spread spectrum modulation techniques and opens the door to performance degradation from "other-user" interference. The penalty for using a thinner antenna (.0254 meter thickness) is negligible for 10 kHz RF bandwidth, 2.7 dB at 3 MHz for 25 kHz bandwidth (but little disadvantage at 5 MHz and above), and approximately 2.5 dB for 100 kHz bandwidth for frequencies from 3 to 5 MHz.

An additional source of degradation, mentioned only briefly in the Introduction, is multipath fading from an HF skywave path between the buoy and receiving sites. Generally, this will be a problem for interference at 370 km ground range only when the ionosphere fully refracts (i.e. reflects back to earth) rays with takeoff angles greater than 25 degrees at a minimum, but more typically in the range of 40 to 60 degrees, at the buoy transmitter. In order for HF skywave interference to occur at a ground range of about 185 km, the ionosphere will have to reflect rays with takeoff angles in the range of 45 to 75 degrees. Since the power radiated at these higher angles by the buoy antenna (which will probably be electrically short at the frequencies of interest for surface wave propagation) will be significantly less than at near- grazing aspect (surface wave direction) and supportive ionospheric conditions will occur infrequently, severe multipath interference from the skywave path should occur only infrequently.

Endorsement of the HF surface wave method of maintaining a continuous data link in the context defined in this report depends strongly upon the required geographical regions of coverage. Obviously, the conclusions of this report are that (a) the performance will be unsatisfactory at low latitude, high noise locations, while (b) the performance will be satisfactory at high latitude sites (such as the Bering Strait) provided the antenna bobbing problem is not more severe than predicted by our simplified analysis. There is definitely a need for experimental data that will quantitatively characterize the effect of mismatch loss caused by antenna bobbing in various states of ocean surface roughness. This data will be strongly dependent upon the dynamical behaviour of the buoy and the design of the insulating jacket around the lower portion of the antenna.

References

1. "Offboard Sensor Communications System (OSCS)," prepared by Booz-Allen & Hamilton Inc. for Naval Sea Systems Command, 28 February 1980.

2. K. Davies, Ionospheric Radio Propagation, National Bureau of Standards Monograph 80, Chapter 4, April 1965.

3. D. E. Barrick, "Theory of Ground-Wave Propagation Across a Rough Sea at Dekameter Wavelengths," DTIC report AD 865840, January 1970.

4. E. C. Hayden, "Delineation of Constraints Imposed by Propagation Factors at HF on Jamming of Ships Communications," prepared for Naval Electronics Systems Command as a final technical report on contract N00039-75-C-0481, project 16-4312, DTIC AD A119491, April 1976.

5. D. E. Barrick, "Theory of HF and VHF propagation across the rough sea, 1, The effective surface impedance for a slightly rough highly conducting medium at grazing incidence," Radio Science, Vol. 6, No. 5, pp 517 - 526, May 1971.

6. D. E. Barrick, "Theory of HF and VHF propagation across the rough sea, 2, Application to HF and VHF propagation above the sea," Radio Science, Vol. 6, No. 5, pp 527 - 533, May 1971.

7. J. W. Ames and W. A. Edson, "Gain, Capture Area, and Transmission Loss for Grounded Monopoles and Elevated Dipoles," Technical Report 2, project 1322, prepared by Stanford Research International under contract SC 900624 for Litton Systems Inc., October 1980.

8. "World Distribution and Characteristics of Atmospheric Radio Noise," CCIR Report 322, published by the International Telecommunication Union, Geneva, 1964.

9. Reference Data For Radio Engineers, Howard W. Sams & Co. Inc., sixth edition, section 24-12 (transmission lines, equation 3), 1975.

10. E. C. Jordan and K. G. Balmain, Electromagnetic Waves and Radiating Systems, second edition, Prentice-Hall, Inc., p. 547, 1968.

11. Handbook of Mathematical Functions, edited by M. Abramowitz and I. Stegun, National Bureau of Standards Applied Mathematics Series 55, pp. 232 - 233, June 1964.

APPENDIX A

Calculation of required power for an earth based transmitter to maintain data rates of 2400 bit/sec and 10,000 bit/sec using a typical UHF satellite with a hard limiting transponder. All parameters assumed as well as those calculated are specified in the following summaries.

Calculations for Data Rate of 2400 bits/second

Type of modulation = DPSK
Required BER = 1×10^{-3}
Required CNR = 43.3 dB-Hz

Earth - Satellite Link Parameters

Transmitter power = 14.2 dBW
Transmission line loss = 2 dB
Anomalous uplink loss = 7 dB
Antenna gain = 0 dB
Uplink frequency = 300 MHz
Uplink distance = 35,900 km

Satellite Parameters

EIRP = 23.0 dBW
Transmission line loss = 0 dB
G/T ratio = -18.0 dB
Satellite channel bandwidth = 25.0 kHz
Downlink frequency (MHz) = 250 MHz

Satellite - to - Earth Link Parameters

Anomalous downlink loss = 7.0 dB
Receiving transmission line loss = 2.0 dB
Receiving antenna gain = 18.0 dB
Receiving antenna temperature = 380 K
Amplifier Noise Figure = 5.0 dB
Downlink distance = 35,900 km

Results of Power Budget Study

Received carrier power = -140.7 dBW
Receiver noise per unit bandwidth = -184.1 dBW
Carrier-to-noise ratio at output of amplifier = 43.4 dB-Hz
System margin = 0.1 dB

Calculations for Data Rate of 10,000 bits/second

Type of modulation = DPSK
Required BER = 1×10^{-3}
Required CNR = 49.5 dB-Hz

Earth - Satellite Link Parameters

Transmitter power = 19.6 dBW
Transmission line loss = 2 dB
Anomalous uplink loss = 7 dB
Antenna gain = 0 dB
Uplink frequency = 300 MHz
Uplink distance = 35,900 km

Satellite Parameters

EIRP = 23.0 dBW
Transmission line loss = 0 dB
G/T ratio = -18.0 dB
Satellite channel bandwidth = 25.0 kHz
Downlink frequency (MHz) = 250 MHz

Satellite - to - Earth Link Parameters

Anomalous downlink loss = 7.0 dB
Receiving transmission line loss = 2.0 dB
Receiving antenna gain = 18.0 dB
Receiving antenna temperature = 380 K
Amplifier Noise Figure = 5.0 dB
Downlink distance = 35,900 km

Results of Power Budget Study

Received carrier power = -138.5 dBW
Receiver noise per unit bandwidth = -188.0 dBW
Carrier-to-noise ratio at output of amplifier = 49.5 dB-Hz
System margin = 0.0 dB

APPENDIX B

This Appendix provides a listing and sample printout of the BASIC program used to calculate the power budget for HF surface wave propagation from an expendable buoy with a monopole antenna. A brief description of the program contents and variable labels is given in the following pages.

One item not discussed previously is the value of directive gain assigned to the transmitting and receiving antennas. We have assumed both antennas to be monopoles and have assigned the values of 5 dB and -1.25 dB as approximate directive gains for the transmitting and receiving antennas, respectively, in accordance with the recommendations of reference [7] which are summarized below.

Antenna Type	Gain (dB)
short monopole	
- transmitting--all cases	4.77
- receiving--space waves	4.77
short monopole	
- receiving surface wave	-1.25
quarter wave monopole	
- transmitting--all cases	5.16
- receiving--space waves	5.16
quarter wave monopole	
- receiving surface wave	-0.86

The specific value assigned for directive gain for either transmission or reception in the surface wave mode may differ depending upon your view of the rest of the propagation scenario. However, the net gain ascribed to the transmitter-receiver combination must agree with experimentally measured power ratios, and this condition is claimed to be satisfied by Ames and Edson [7] for the gains quoted above. The computations in this report depend only on the combined gain and not the individual values set for transmitting or receiving.

Two geographical areas were considered when making these calculations, the Bering Strait and Cuba (see Stmt. 875 to determine the location). The propagation distance (DD) was fixed at 150 N. miles (27.8E4 meters) for this set of calculations, although some additional calculations were done for 100 and 200 nautical mile ranges (see Stmt. 860). For each location, two RF bandwidths were considered--10 KHz or 100 KHz (see Stmt. 860 where BT is set). The antenna height was fixed at 5 meters, the diameter at .2 meters (see Stmt. 600). For each bandwidth, the program was run for each of four different frequencies (3, 5, 7, or 10 MHz). The frequency for any particular run is read in from a data statement (see Stmts. 163 and 7780-7835). Further, for each individual frequency, a separate run was made for each of three sea states (0, 4, and 6). The twenty-four hour day was divided into 6 time blocks of 4 hours each. For each location and for each of the six time blocks a best case noise level (when the noise levels were at their lowest) and a worst case noise level (when the noise levels were at their highest) was determined. Each run of the program produced

results for each of the 6 best and 6 worst case time blocks in a particular location for each of the sea states within each of the frequencies.

```
100 REM PROGRAM CALCULATES RADIATION RESISTANCE AND REACTANCE OF
A
120 REM MONOPOLE ANTENNA OF HEIGHT "H" AND THICKNESS "D"
130 REM RADIATION RESISTANCE IS FROM AN IMPERICAL FIT TO GRAPHICAL
140 REM DATA OF JORDAN & BALMAIN (P. 548)
150 REM REACTANCE IS FROM EQUATIONS OF JORDAN & BALMAIN (P. 546-7)
151 REM THE MAIN PROGRAM (STMTS. 160-810) READS IN 12 DATA
152 REM STATEMENTS WHICH FILL VARIABLES FOR ENVIRONMENTAL NOISE
153 REM (FA), PROPAGATION LOSS (LZ), FREQUENCY (F), SEA STATE (SS)
154 REM AND TIME BLOCK (TB$). STATEMENTS 100-810 CALCULATE ANTENNA
155 REM REACTANCE AND/OR CAPACITANCE. THE MAIN PROGRAM INVOKES A
156 REM SUBPROGRAM (PROG2) WHICH COMPLETES OTHER CALCULATIONS
AND
157 REM PRODUCES A WRITTEN REPORT (SEE STMTS. 812-821 FOR AN
158 REM EXPLANATION OF PROG2'S INPUT PARAMETERS AND STMTS. 823-827
159 REM FOR A DESCRIPTION OF THE CALCULATIONS PERFORMED BY PROG2).

160 PI=3.141592654#
161 DR=2400

162 REM READ 12 DATA STATEMENTS

163 FOR ZZ=1 TO 12 : READ FA,LZ,F,SS,TB$ : FOR I=1 TO 8 : LPRINT " " : NEXT I
170 GOTO 600
180 REM SUBROUTINE 180
190 IF X<1 THEN 510
260 A1=38.027264#: B1=40.021433#
265 A2=265.187033#: B2=322.624911#
270 A3=335.67732#: B3=570.23628#
275 A4=38.102495#: B4=157.105423#
280 C1=42.242855#: D1=48.196927#
285 C2=302.757865#: D2=482.485984#
290 C3=352.018498#: D3=1114.978885#
295 C4=21.821899#: D4=449.690326#
300 X2=X*X: X4=X2*X2: X6=X4*X2: X8=X4*X4
410 N1=A4+A3*X2+A2*X4+A1*X6+X8
420 Z1=B4+B3*X2+B2*X4+B1*X6+X8
430 FX=N1/(Z1*X)
440 N2=C4+C3*X2+C2*X4+C1*X6+X8
450 Z2=D4+D3*X2+D2*X4+D1*X6+X8
460 GX=N2/(Z2*X*X)
470 SX=PI/2-FX*COS(X)-GX*SIN(X)
475 CI=FX*SIN(X)-GX*COS(X)
500 GOTO 540
```

```
510 X2=X*X: X3=X2*X: X5=X3*X2: X7=X5*X2
515 X4=X2*X2: X6=X3*X3: X8=X4*X4
520 SX=X-X3/18+X5/600-X7/35280!
530 CX=.5772156649#+LOG(X)-X2/4+X4/96-X6/4320+X8/322560!
540 RETURN
600 H=5! : D=.2
605 WL=3E+08/F
606 HW=H/WL: AW=D/(2*WL): K2=HW*HW: K4=K2*K2
610 BT=2*PI*F/3E+08
620 BH=BT*H: H2=2*BH: H4=4*BH
625 RR=400*K2+3700*K4: REM RADIATION RESISTANCE
630 AZ=D*D/4
640 X=H2: GOSUB 180
645 W1=SX: W2=CX
650 X=H4: GOSUB 180
655 W3=SX: W4=CX
660 T1=-.5772156649#+LOG(H/(BT*AZ))+2*W2-W4
665 T2=2*W1-W3
670 T3=SIN(H2)*T1-COS(H2)*T2-2*W1
680 XX=-15*T3/(SIN(BH)^2)
681 IF XX >= 0 THEN PRINT "ANTENNA INDUCTIVE"  ELSE 685
682 GOTO 810
685 LPRINT "H=";H;"D=";D;"F=";F
686 LPRINT"H/LAMBDA= ";USING"#.####";HW
687 LPRINT"RADIUS/LAMBDA= ";USING"#.####^^^^";AW
688 LPRINT"RADIATION RESISTANCE= ";USING"##.###^^^^";RR
690 IF SGN(XX)>0 THEN 730: REM INDUCTIVE CONDITION
700 AC=-1/(2*PI*F*XX)
710 LPRINT "XX=";XX;"AC=";AC : GOTO 805
730 L=XX/(2*PI*F)
740 LPRINT "XX=";XX;"L=";L
741 REM INVOKING PROG2
805 CALL PROG2(F,SS,DR,FA,AC,H,D,LZ,TB$)
806 NEXT ZZ
810 END


812 REM THIS IS THE PROG2 SUBPROGRAM. ITS INPUT PARAMETERS ARE:
813 REM  F--FREQUENCY (3,5,7, OR 10) (HZ)
814 REM  SS--SEA STATE (0,2,4, OR 6)
815 REM  DR--DATA RATE AT WHICH DATA IS TO BE TRANSFERRED (BPS)
816 REM  FA--ENVIRONMENTAL NOISE FIGURE (DB)
817 REM  AC--ANTENNA CAPACITANCE
818 REM  H--ANTENNA LENGTH (M)
819 REM  D--ANTENNA THICKNESS (M)
820 REM  LZ--PROPAGATION LOSS (DB)
821 REM  TB$--TIME BLOCK STRING
```

```
822 SUB PROG2(F,SS,DR,FA,AC,H,D,LZ,TB$) STATIC

823 REM PROG2 CALCULATES MATCHING INDUCTANCE, TOTAL RESISTIVE
LOSS
824 REM OF THE ANTENNA AND THE MATCHING NETWORK, LOSS IN THE
825 REM TRANSMITTINGANTENNA CIRCUIT, TOTAL NOISE FIGURE, SIGNAL TO
826 REM NOISE RATIOS AND FINALLY, THE REQUIRED POWER TO TRANSMIT
THE
827 REM DATA AT A DATA RATE (FIXED) OF 2400 BITS PER SECOND.
828 REM ***   S-BUOY LINK  CALCULATIONS   ***
830 REM ***   E L ALTHOUSE 12/10/84   ***
835 PI=3.1415927#: CC=3E+08:  KT=4E-21
840 L0=LOG(10)
850 PT=15 : GT=5! : RG=50!
860 BT=100000! : BF=2! : DD=278000!
870 GR=-1.25 : FR=3! : FM=2! : FT=1!
875 L$="BERING STRAIT"
880 REM L$=LOCATION OF FA READING
888 REM SS=SEA STATE DESCRIPTOR (1-6)
890   REM GT=DIRECTIVE GAIN OF XMIT ANT (DB)
895    REM PT=REQUIRED DRIVER POWER(WATTS)
900    REM RG=INTERNAL RESISTANCE OF DRIVER
905    REM RL=LOSS RESISTANCE OF ANTENNA & MATCH NETWORK
910     REM H=ANT LENGTH (M)
915     REM D=ANT THICHNESS (M)
920     REM AC=ANTENNA CAPACITANCE (F)
925    REM F=FREQ (HZ)
930     REM BT=XMIT RF BW (HZ)
935    REM DR=DATA RATE (BPS)
940    REM DD=PROPAGATION DIST (M)
950   REM GR=PWR GAIN (DB) OF RCV ANT
955    REM FR= NOISE FIGURE (DB) OF RECEIVER
960   REM FM=NOISE FIG (LOSS, DB) OF RCV MATCH NETWORK
970   REM FT=NOISE FIG (LOSS,DB) OF RCV XMISSION LINE
980    REM FA=ENVIRONMENTAL NOISE FIGURE (DB)
990  REM BF = RF BAND FLATNESS (DB)
1000 W=2*PI*F
1005 LM=1/(W*W*AC): REM MATCH INDUCTANCE AT CF
1010 T9=2*F/BT
1015 EH=10^(BF/10)
1020 AK=PI*LM*BT*(1+2*T9)/(1+T9)/2
1025 REM CALC RADIATION RESIST. (SHORT(<=1/4WL)MONOPOLE ASSUMED)
1030 ZF=H*H*F*F
1035 RR=ZF*(4.444E-15)*(1+(1.0279E-16)*ZF)
1040 REM RR=RAD RESIST. OF XMIT ANT
```

```
1050 RL=AK/SQR(EH-1)-RR
1060 IF RL<1 THEN RL=1
1070 RT=RR+RL: REM TOTALREST LOSS OF ANT & MATCH NW
2140 REM ASSUME WE CAN PERFECTLY MATCH ANTENNA IMPEDANCE
2150 REM (RR+RL) UP TO 10*RG AND DOWN TO RG/10
2160 N2=RG/RT
2170 IF N2>10 THEN N2=10
2180 IF N2<.1 THEN N2=.1
2190 REM CALC LOSS IN XMIT ANT CIRCUIT
2195 R1=((RT+RG/N2)^2)
2200 R2=4*RR*RG/N2
2210 L1=(R1+(W*LM-1/(W*AC))^2)/R2
2220 W1=(F-BT/2)*PI*2: U2=W1*LM-1/(W1*AC)
2225 L2=(R1+U2^2)/R2
2230 W2=(F+BT/2)*PI*2: U3=W2*LM-1/(W2*AC)
2235 L3=(R1+U3^2)/R2
2240 REM L1=LOSS AT CENTER RF
2245 REM L2=LOSS AT LOW RF
2250 REM L3=LOSS AT HIGH RF
2270 FL=0: REM SET FLAG
3230 GOTO 3255
3240 LL=(4*PI*F*DD/CC)^2: GOTO 3260
3255 LL=10^(LZ/10)
3260 GZ=10^(GR/10)
3265 FZ=10^(FR/10)
3270 FY=10^(FM/10)
3275 FX=10^(FT/10)
3280 FW=10^(FA/10)
3285 DG=10^(GT/10)
3290 FF=FW-1+FX*FY*FZ: REM TOTAL NOISE FACTOR
3300 REM COMPUTE NOISE IN BW=BD
3310 ND=KT*FF
3320 REM COMPUTE SNR'S
3330 T1=PT*DG*GZ/(LL*FY*FX*ND*2*DR)
3340 S1=10*LOG(T1/L1)/L0
3350 S2=10*LOG(T1/L2)/L0
3360 S3=10*LOG(T1/L3)/L0
3361 SM=S1
3362 IF SM >= S2 THEN SM=S2
3363 IF SM >= S3 THEN SM=S3

3370 REM  THIS PORTION OF CODE COMPUTES THE NEEDED POWER TO
6375 REM  TRANSMIT AT A DATA RATE OF 2400 BPS. THE CODE ALSO
6380 REM  ASSURES THAT THE SIGNAL TO NOISE RATIOS (SNR'S) WILL BE
6385 REM  AS CLOSE AS POSSIBLE TO 13 dB.
```

```
6400 X1=13-S2
6410 PT=PT*20/(10^(SM/10))
6420 T1=PT*DG*GZ/(LL*FY*FX*ND*2*DR)
6430 S1=10*LOG(T1/L1)/L0
6440 S2=10*LOG(T1/L2)/L0
6450 S3=10*LOG(T1/L3)/L0
6500 CLS: O1=10: O2=15: O3=20
6510 LPRINT TAB(10)"  S-BUOY LINK CALCULATIONS"
6520 LPRINT" "
6530 LPRINT TAB(O2)"MONOPOLE ANTENNA ASSUMED"
6550 LPRINT TAB(O3)"ANT LENGTH (M) =";USING"##.##";H;
6560 LPRINT"   (";USING"##.##";H/.3048;
6570 LPRINT " FT)"
6580 LPRINT TAB(O3)"ANT THICKNESS (M) =";USING"#.####";D;
6590 LPRINT"  (";USING"##.###";D/.0254;
6600 LPRINT " INCHES)"
6610 LPRINT TAB(O3)"ASSOC. CAPACITANCE (F) =";USING"##.###^^^^";AC
6620 LPRINT TAB(O3)"ASSUMED DIRECTIVE GAIN (DB) = ";USING"##.##";GT
6630 LPRINT" "
6650 LPRINT TAB(O2)"REQUIRED DRIVER PWR (W) =";USING"###.##^^^^";PT
6660 LPRINT TAB(O2)"INTERNAL RESIST. OF DRIVER =";USING"###.##";RG
6665 LPRINT TAB(O2)"RESISTIVE LOSS NEEDED FOR DESIRED RF BW=";
6666 LPRINT USING"##.##";RL
6670 LPRINT TAB(O2)"TOTAL LOSS  RESISTANCE OF ANT & (REFLECTED)
MATCH NW = ";
6680 LPRINT USING"###.##";RL+RG/N2
6685 LPRINT TAB(O2)"RADIATION RESIST. = ";USING"##.###^^^^";RR
6690 LPRINT TAB(O2)"MATCHING IMPED. RATIO = ";USING"##.##";N2
6695 LPRINT TAB(O2)"MATCHING INDUCTANCE (H) =";USING"#.###^^^^";LM
6700 LPRINT TAB(O2)"NET REACTANCE AT LOW RF = ";USING"#####.##";U2
6705 LPRINT TAB(O2)"NET REACTANCE AT HIGH RF = ";USING"#####.##";U3
6710 LPRINT TAB(O2)"FRACT WAVELNTHS OF ANT = ";
6720 LPRINT USING"#.###^^^^";H*F/CC
6730 LPRINT" "
6740 LPRINT TAB(O2)"FREQUENCY (HZ) = ";USING"##.###^^^^";F
6750 LPRINT TAB(O2)"TRANSMIT RF BW (HZ) = ";USING"##.###^^^^";BT
6760 LPRINT TAB(O2)"DATA RATE (BPS) = ";USING"##.###^^^^";DR
6800 Y$="(CALCULATED FREE SPACE LOSS)"
6801 X$="(USER-SUPPLIED VALUE)"
6810 LPRINT TAB(O2)"PROPAGATION DIST (M) = ";USING"###.###^^^^";DD;
6815 LPRINT "  (";USING"####.##";DD/1852;
6816 LPRINT" N. MILES)"
6819 LPRINT TAB(O2)"SEASTATE # = ";USING"#.#";SS
6820 LPRINT TAB(O2)"PROGAGATION LOSS (DB) = ";
6830 LPRINT USING"###.##";10*LOG(LL)/L0;
6840 IF FL=0 THEN LPRINT Y$
```

```
6845 IF FL=1 THEN LPRINT X$
6850 LPRINT TAB(O2)"MATCHING LOSS (DB) AT CENTER RF = ";
6855 LPRINT USING"###.##";10*LOG(L1)/L0
6860 LPRINT TAB(O2)"MATCHING LOSS AT LOW RF = ";
6870 LPRINT USING"###.##";10*LOG(L2)/L0
6880 LPRINT TAB(O2)"MATCHING LOSS AT HIGH RF = ";
6900 LPRINT USING"###.##";10*LOG(L3)/L0
6960 LPRINT" "
6970 LPRINT TAB(O2)"RCV ANT POWER GAIN (DB) = ";USING"##.##";GR
6980 LPRINT TAB(O2)"NOISE FIG OF RCV MATCH NW (DB) = ";
6981 LPRINT USING"##.##";FM
6990 LPRINT TAB(O2)"NOISE FIG OF RCV XMISSION LINE (DB) = ";
7000 LPRINT USING"##.##";FT
7700 LPRINT TAB(O2)"NOISE FIG OF RECIEVER (DB) = ";USING"##.##";FR
7705 LPRINT TAB(O2)"CASE AND TIME BLOCK: ";TB$
7710 LPRINT TAB(O2)"ENVIRONMENTAL NOISE FIG (DB) = ";USING"##.##";FA
7715 LPRINT TAB(O2)"GEOGRAPHICAL POSITION:  ";L$
7720 LPRINT TAB(O2)"COMPOSITE NOISE FIG (DB) = ";
7721 LPRINT USING"##.##";10*LOG(FF)/L0
7730 LPRINT" "
7740 LPRINT TAB(O2)"NOISE SPECTRAL DENSITY AT RCVR (W/HZ) = ";
7741 LPRINT USING"##.###^^^^";ND
7750 LPRINT TAB(O2)"SNR (DB) AT CENTER RF = ";USING"##.##^^^^";S1
7760 LPRINT TAB(O2)"SNR (DB) AT LOW RF = ";USING"##.##^^^^";S2
7770 LPRINT TAB(O2)"SNR (DB) AT HIGH RF = ";USING"##.##^^^^";S3
7775 LPRINT TAB(O2)"(NOTE: THESE SNR'S ARE FOR DIRECT USE IN FSK";
7776 LPRINT " AND M-ARY CHARTS OF Pe VS SNR)"
7777 LPRINT CHR$(12)
```

These are the data statements for the program. The first number on each line is the environmental noise figure for a particular location during the noted time block. The second entry on the data line is the propagation loss determined for this particular sea state and frequency. The third entry is the frequency to be used in this run. The next number is the sea state being considered while the last entry on the data line is the time block. For this run, the frequency was set for 3 MHz, the sea state was chosen to be 0. The propagation loss for 3 MHz, Sea State 0, and a 150 N. mile range is 99 dB, and for each worst and best case time block, the noise figure is as noted. Other variables that can be set by the user are: the geographical location (Stmt. 875), the RF bandwidth (BT in Stmt. 860), and the propagation distance (DD in Stmt. 860). For this particular run these are set at Bering Strait, 100 KHz, and 150 N. miles (27.8E4) respectively.

```
7780 DATA 55.6,99,3E6,0, WORST/0000-0400
7785 DATA 53.0,99,3E6,0, WORST/0400-0800
7790 DATA 25.7,99,3E6,0, WORST/0800-1200
```

```
7795 DATA 29.0,99,3E6,0, WORST/1200-1600
7800 DATA 51.6,99,3E6,0, WORST/1600-2000
7805 DATA 54.8,99,3E6,0, WORST/2000-2400
7810 DATA 52.6,99,3E6,0, BEST/0000-0400
7815 DATA 35.8,99,3E6,0, BEST/0400-0800
7820 DATA 24.0,99,3E6,0, BEST/0800-1200
7825 DATA 25.3,99,3E6,0, BEST/1200-1600
7830 DATA 34.8,99,3E6,0, BEST/1600-2000
7835 DATA 51.9,99,3E6,0, BEST/2000-2400
9000 END SUB
```

Example of Printout from BASIC Program

H(antenna height) = 5 meters
D(antenna thickness) = 0.200 meters (7.87 inches)
Assumed directive gain = 5.00 dB
F(frequency) = 3000000 Hz
H/LAMBDA = 0.0500
(Antenna half-radius)/LAMBDA = .00100
Radiation resistance = 1.023 ohms
XX = -574.413 ohms
AC = 9.2358E-11 Farads
Required data rate = 2400 BPS
Required instantaneous RF bandwidth = 100 kHz
Propagation distance = 278.0 km (150.1 N. miles)
Internal resistance of driving amplifier = 50.0 ohms
Resistive loss needed for desired RF bandwidth = 11.39 ohms
Total loss resistance of antenna and (reflected) matching network = 23.81 ohms
Impedance ratio required for matching = 4.03
Matching inductance required = .305E-4 Henries
Matching loss at center of RF band = 10.84 dB
Matching loss at low RF = 12.89 dB
Matching loss at high RF = 12.84 dB
Net reactance at low RF = -19.31 ohms
Net reactance at high RF 18.99 ohms

Assumptions about receiving system

Antenna power gain = -1.25 dB
Noise figure of receiver matching network = 2.0 dB
Noise figure of receiving transmission line = 1.0 dB
Noise figure of receiver = 3.0 dB

Environmental conditions

Sea state = 0
Environmental noise figure = 55.6 dB

Results

Noise spectral density at receiver = 1.452E-15 Watts/Hz
Required driver power = 18.15 Watts
SNR at center of RF band = 15.1 dB
SNR at low end of RF band = 13.0 dB
SNR at high end of RF band = 13.1 dB

APPENDIX C

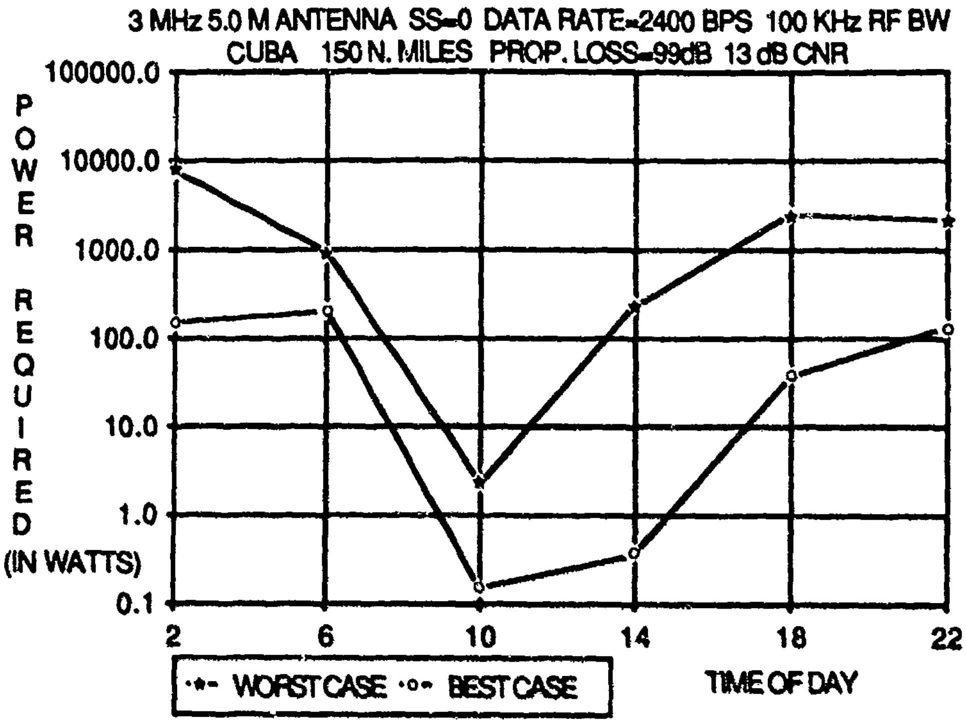
The figures in this appendix (pages C-2 to C-13) show the predictions of required driver power for the buoy antenna at a range of 278 km (150 n. miles) for a low latitude geographical location near Cuba. A data rate of 2400 bits/sec and an RF bandwidth of 100 kHz are assumed. The required power is plotted as a function of time of day in units of 4-hour time blocks. A built-in limitation in the plotting software package prevented the time axis from spanning the full range of 0 to 24 hours; however, it should be understood that the full 24 hour time period is intended for the graphs. The highest set of connected points apply to the case of lowest seasonal noise while the lowest set of points apply to highest seasonal noise. The data below the graphs show the actual environmental noise values used in the calculations for each time block. The table below shows the surface wave propagation attenuations used for this range as a function of frequency and sea state.

GROUND WAVE LOSS
(REFERENCE : BARRICK)

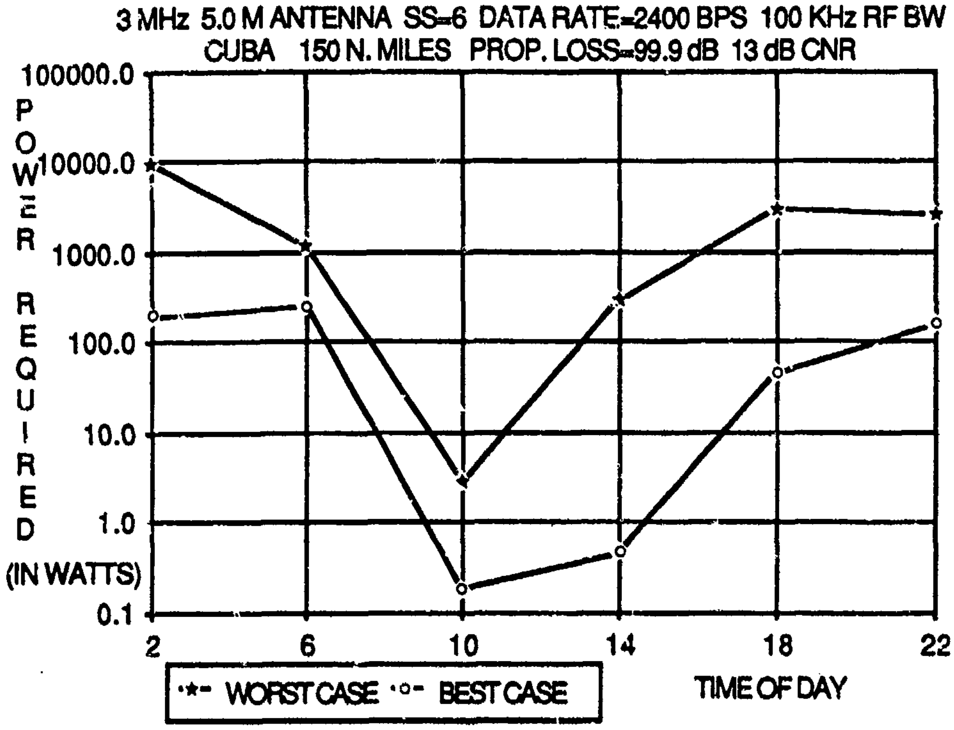
150 N. MILE (277.8 KM) RANGE

		Neumann-Pierson Upwind-Downwind			Neumann-Pierson Cross-Wind			Phillips Isotropic Spectrum		
FREQ (MHz)	BASIC LOSS (dB)	SS 2	SS 4	SS 6	SS 2	SS 4	SS 6	SS 2	SS 4	SS 6
3	93	-.25	-.75	.9	-.05	-.25	-.45	-.4	1.05	.05
5	102	-.20	.90	6.1	-.1	-.3	1.4	-.7	.6	2.8
7	108.5	0	3.7	12.5	0	.9	3.8	-.7	3.2	6.8
10	119	.7	8.6	19.6	0	2.8	7.9	0.8	7.8	13.0
				TOTAL LOSS VS. SEASTATE						
3	93	92.7	92.2	93.9	92.9	92.7	92.5	92.6	92.0	93.1
5	102	101.8	102.9	108.1	101.9	101.7	103.4	101.3	102.6	104.8
7	108.5	108.5	112.2	121.0	108.5	109.4	112.3	107.8	111.7	115.3
10	119	119.7	127.8	128.6	119	121.8	126.5	119.8	126.6	132.0

NOTE : 6 dB MUST BE ADDED TO BARRICK'S VALUES IN ORDER TO BE CONSISTENT WITH THE STANDARD WAY OF SPECIFYING ANTENNA GAIN.

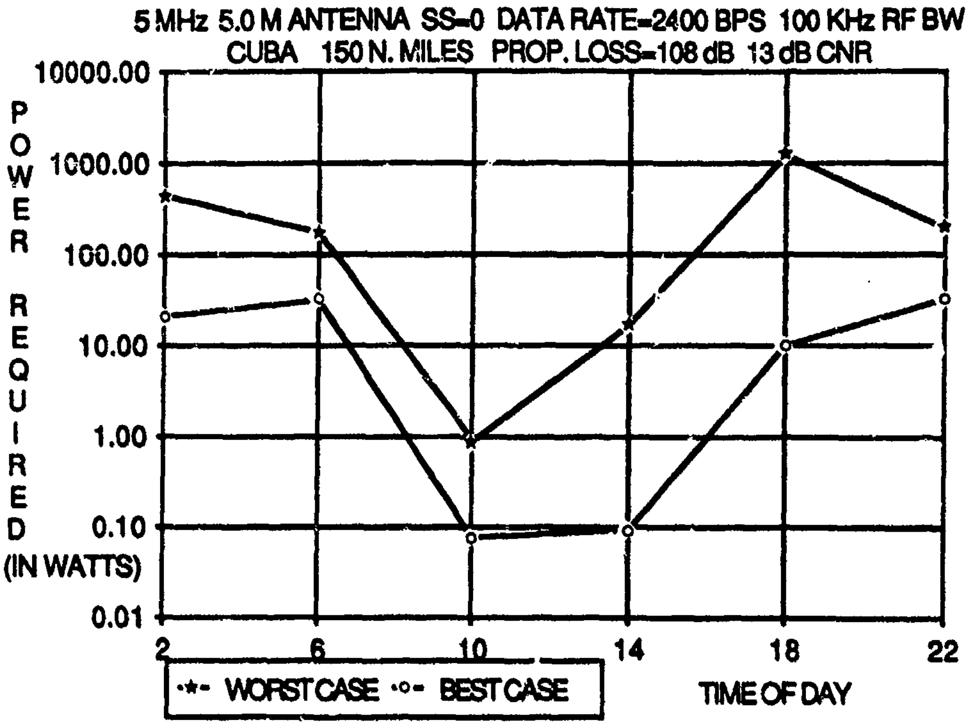


TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	81.8
0400-0800	72.5
0800-1200	46.6
1200-1600	66.6
1600-2000	76.9
2000-2400	76.1
BEST CASE	
0000-0400	64.8
0400-0800	66.0
0800-1200	34.8
1200-1600	38.7
1600-2000	58.5
2000-2400	64.1

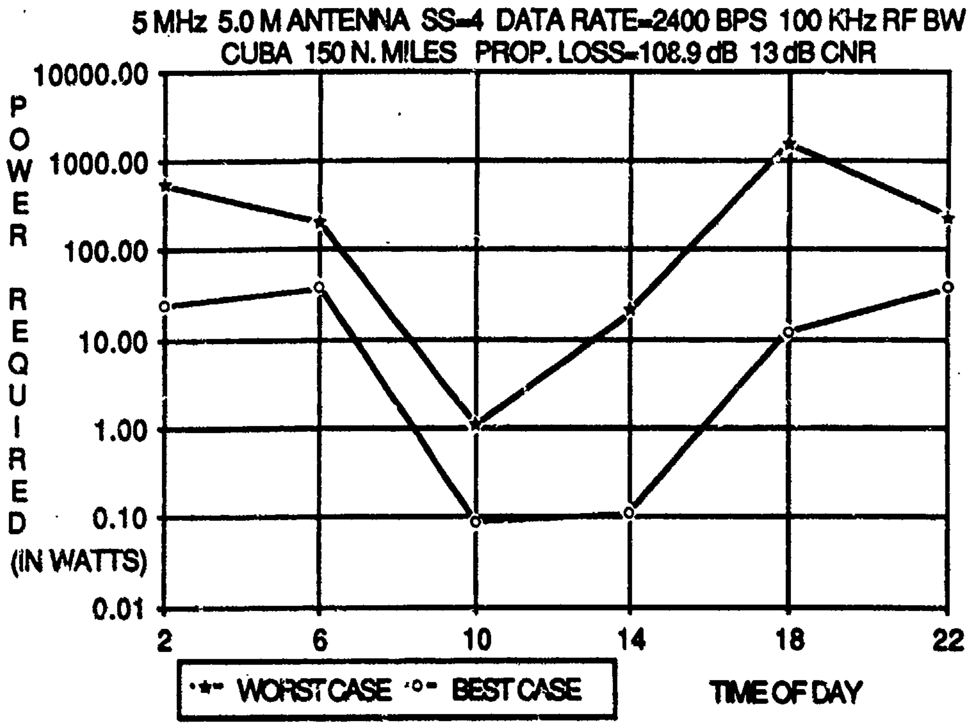


TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	81.8
0400-0800	72.5
0800-1200	46.6
1200-1600	66.6
1600-2000	76.9
2000-2400	76.1
BEST CASE	
0000-0400	64.8
0400-0800	66.0
0800-1200	34.8
1200-1600	38.7
1600-2000	58.5
2000-2400	64.1

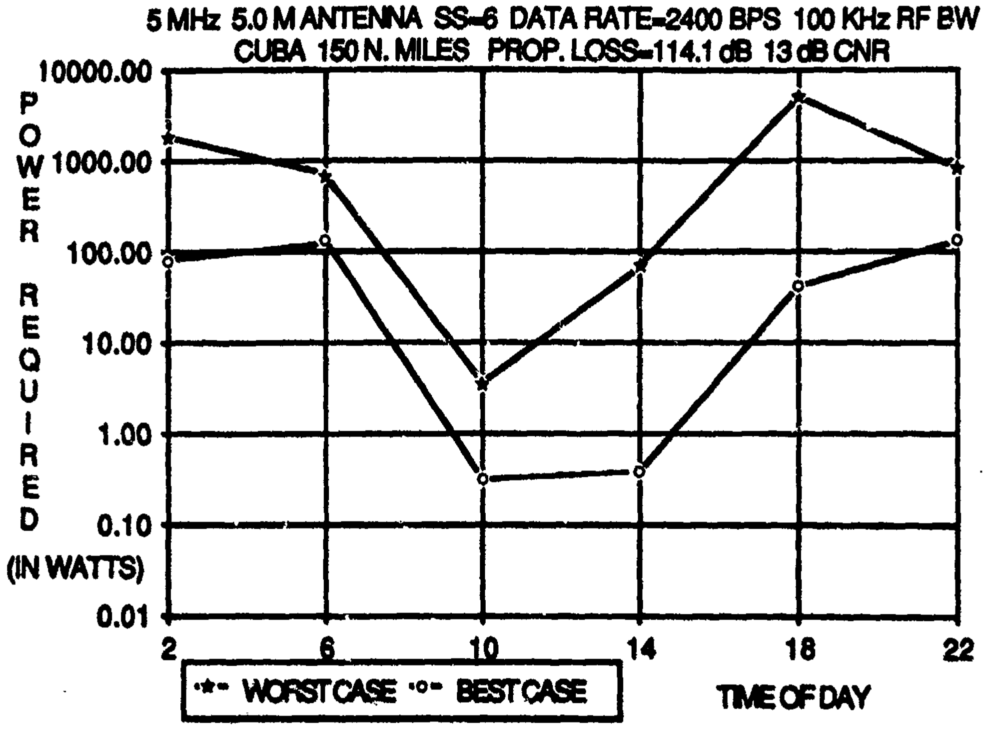
yh



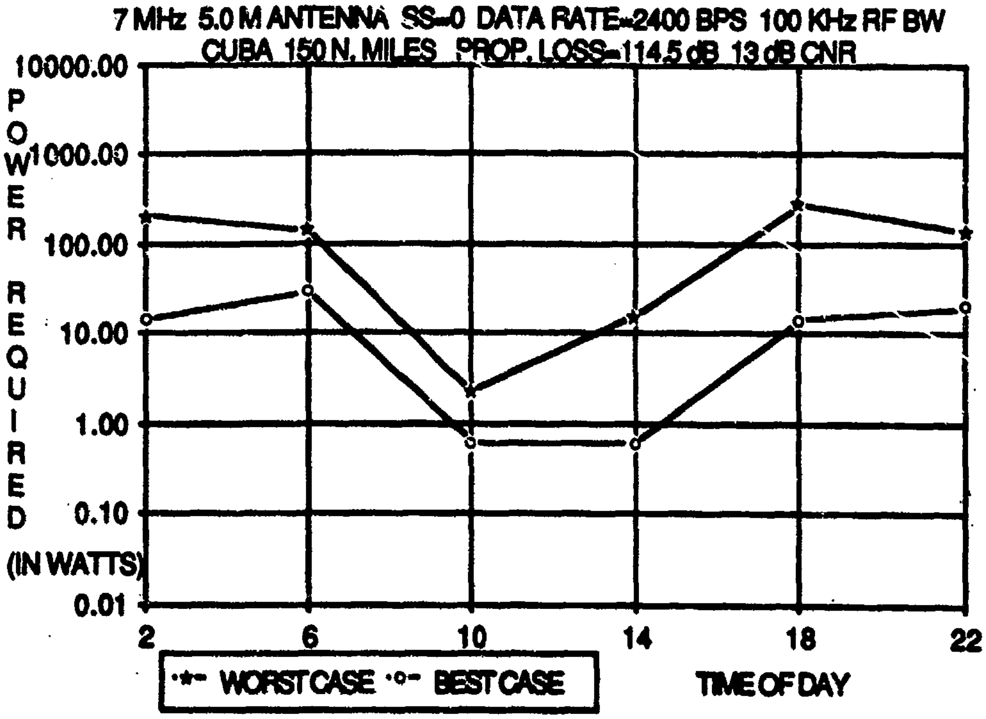
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	70.5
0400-0800	66.2
0800-1200	43.5
1200-1600	56.3
1600-2000	74.9
2000-2400	66.9
BEST CASE	
0000-0400	57.1
0400-0800	59.1
0800-1200	32.8
1200-1600	33.8
1600-2000	54.1
2000-2400	59.1



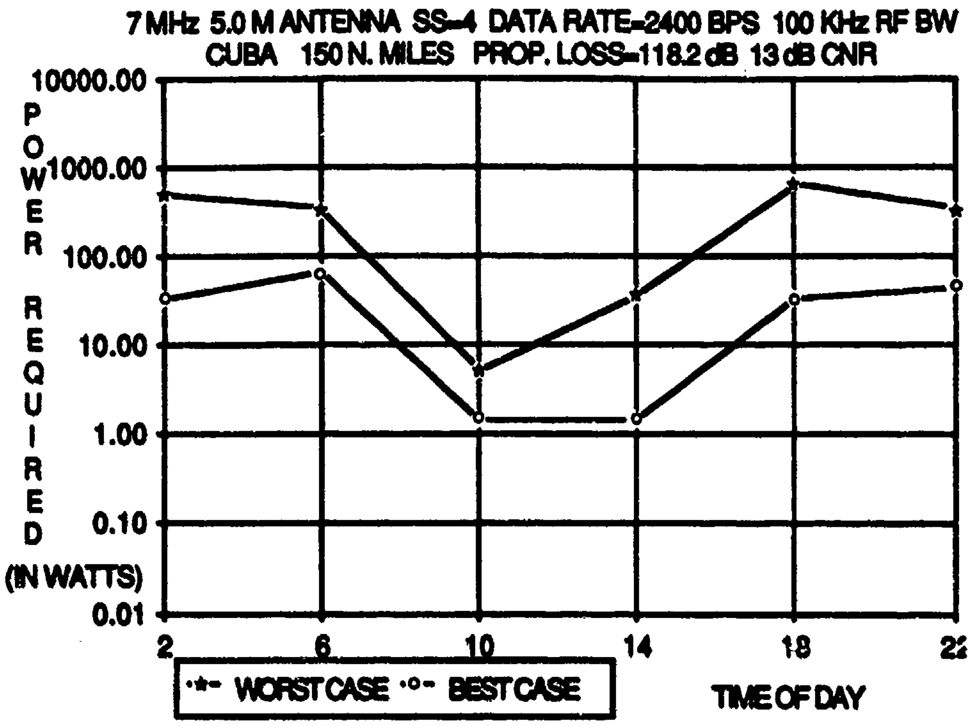
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	70.5
0400-0800	66.2
0800-1200	43.5
1200-1600	56.3
1600-2000	74.9
2000-2400	66.9
BEST CASE	
0000-0400	57.1
0400-0800	59.1
0800-1200	32.8
1200-1600	33.8
1600-2000	54.1
2000-2400	59.1



TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	70.5
0400-0800	66.2
0800-1200	43.5
1200-1600	58.3
1600-2000	74.9
2000-2400	66.9
BEST CASE	
0000-0400	57.1
0400-0800	59.1
0800-1200	32.8
1200-1600	33.8
1600-2000	54.1
2000-2400	59.1

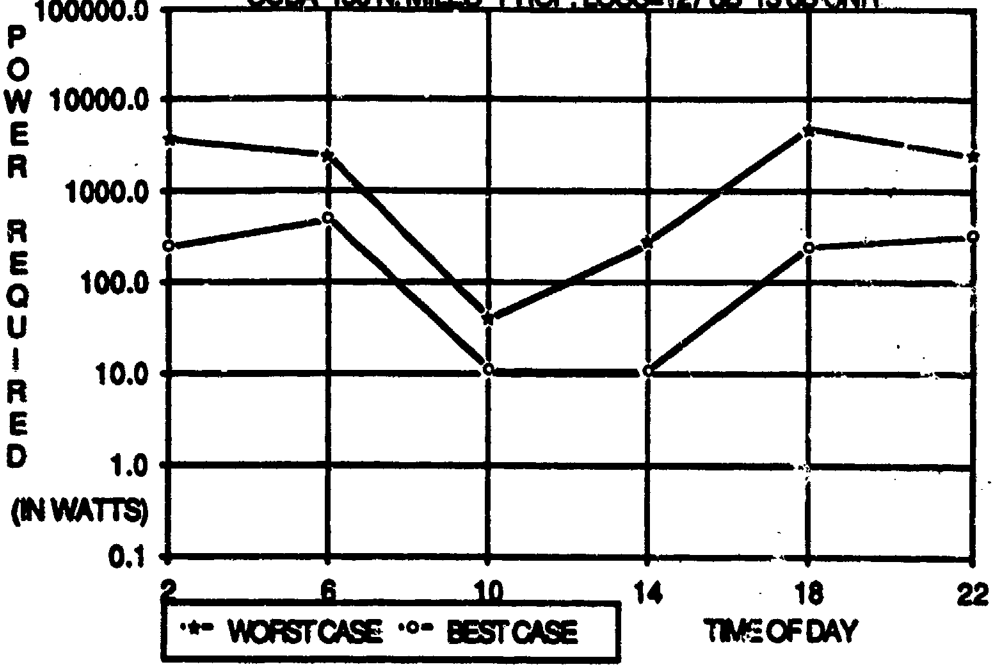


TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
<u>WORST CASE</u>	
0000-0400	62.8
0400-0800	61.0
0800-1200	43.0
1200-1600	51.5
1600-2000	64.0
2000-2400	61.0
<u>BEST CASE</u>	
0000-0400	51.1
0400-0800	54.2
0800-1200	37.5
1200-1600	37.5
1600-2000	51.1
2000-2400	52.5

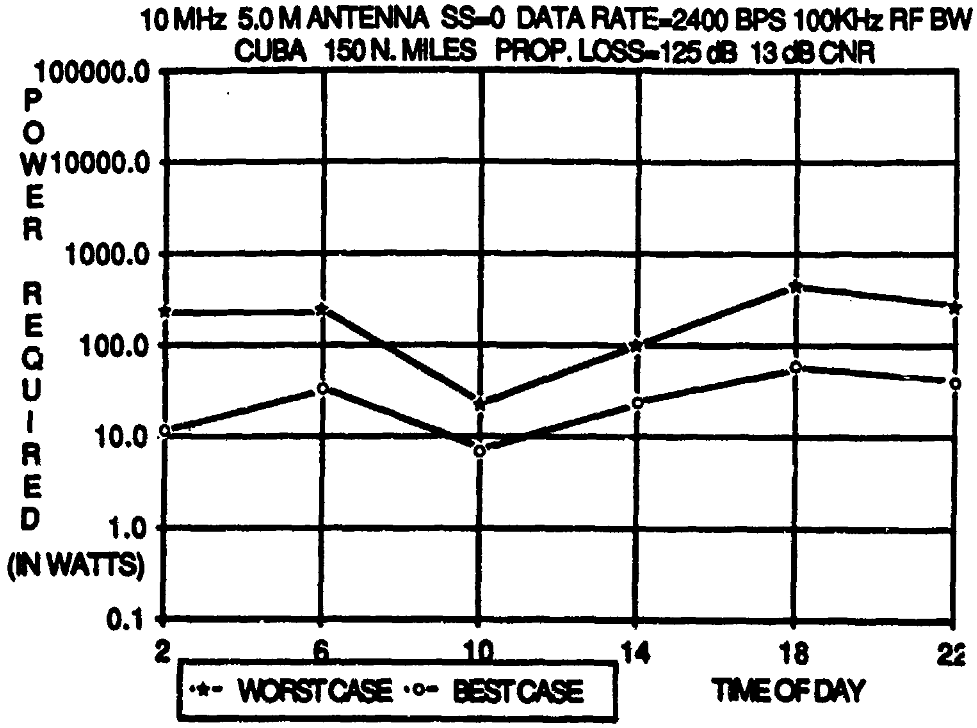


TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	62.8
0400-0800	61.0
0800-1200	43.0
1200-1600	51.5
1600-2000	64.0
2000-2400	61.0
BEST CASE	
0000-0400	51.1
0400-0800	54.2
0800-1200	37.5
1200-1600	37.5
1600-2000	51.1
2000-2400	52.5

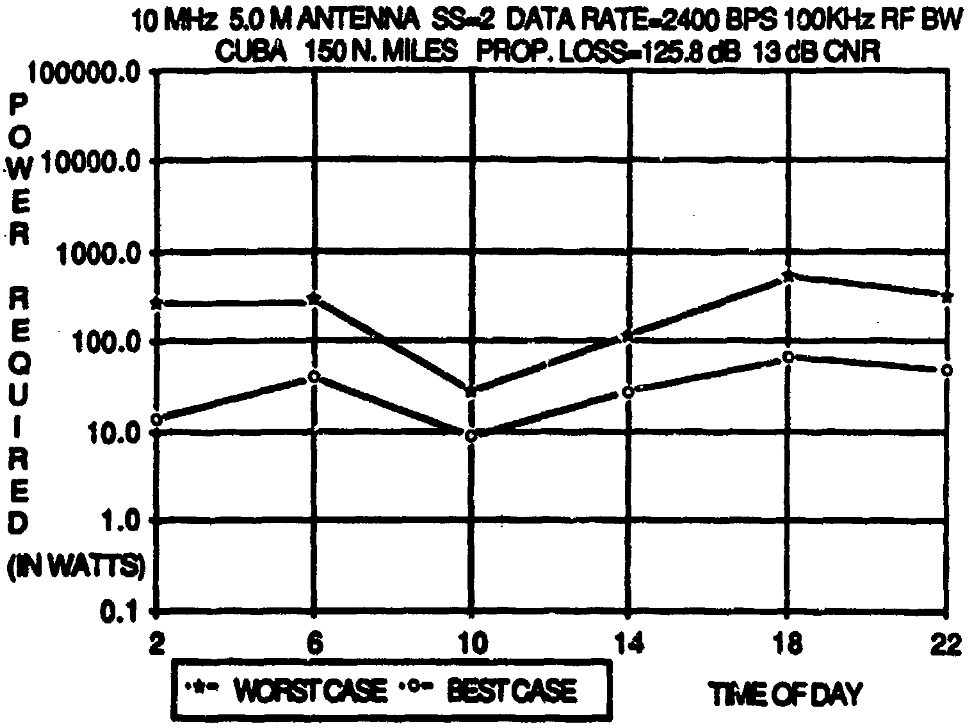
7MHz 5.0 M. ANTENNA SS-6 DATA RATE=2400 BPS 100KHz RFBW
CUBA 150 N. MILES PROP. LOSS=127 dB 13 dB CNR



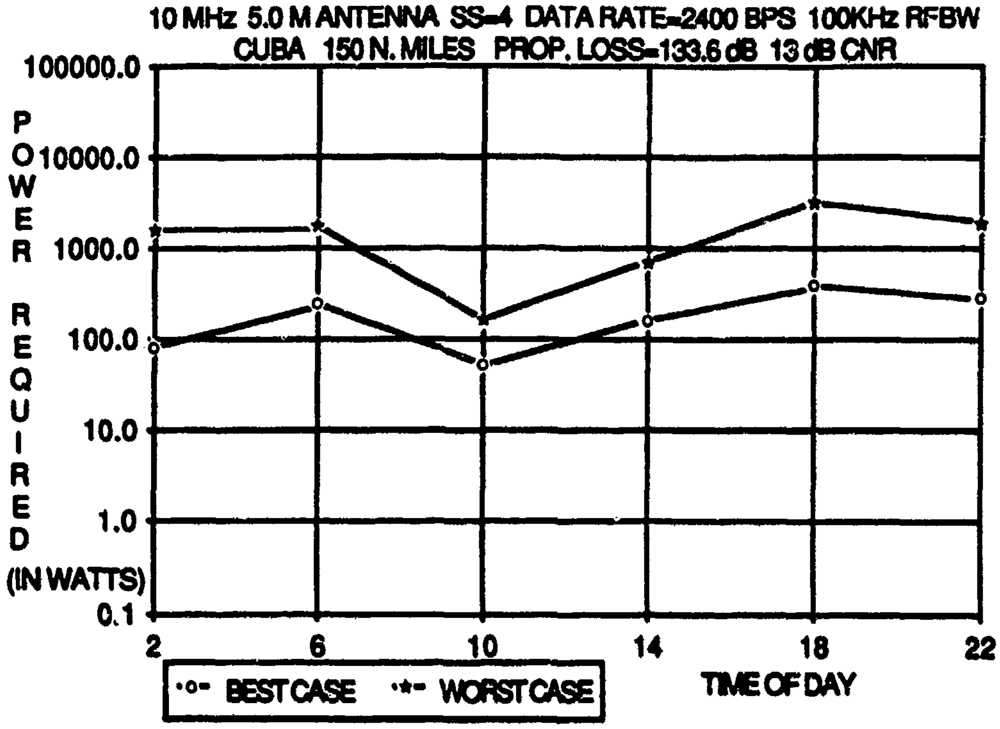
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	62.8
0400-0800	61.0
0800-1200	43.0
1200-1600	51.5
1600-2000	64.0
2000-2400	61.0
BEST CASE	
0000-0400	51.1
0400-0800	54.2
0800-1200	37.5
1200-1600	37.5
1600-2000	51.1
2000-2400	52.5



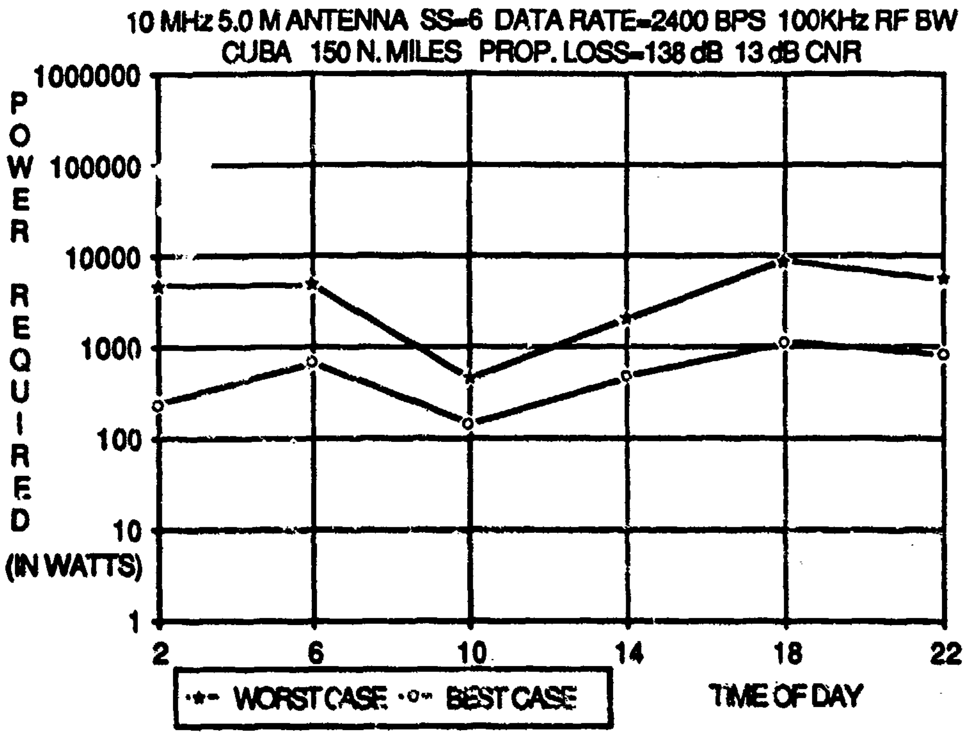
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
<u>WORST CASE</u>	
0000-0400	53.1
0400-0800	53.2
0800-1200	43.0
1200-1600	49.5
1600-2000	56.0
2000-2400	53.7
<u>BEST CASE</u>	
0000-0400	40.2
0400-0800	44.7
0800-1200	38.0
1200-1600	43.2
1600-2000	47.0
2000-2400	45.5



TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	53.1
0400-0800	53.2
0800-1200	43.0
1200-1600	49.5
1600-2000	56.0
2000-2400	53.7
BEST CASE	
0000-0400	40.2
0400-0800	44.7
0800-1200	38.0
1200-1600	43.2
1600-2000	47.0
2000-2400	45.5



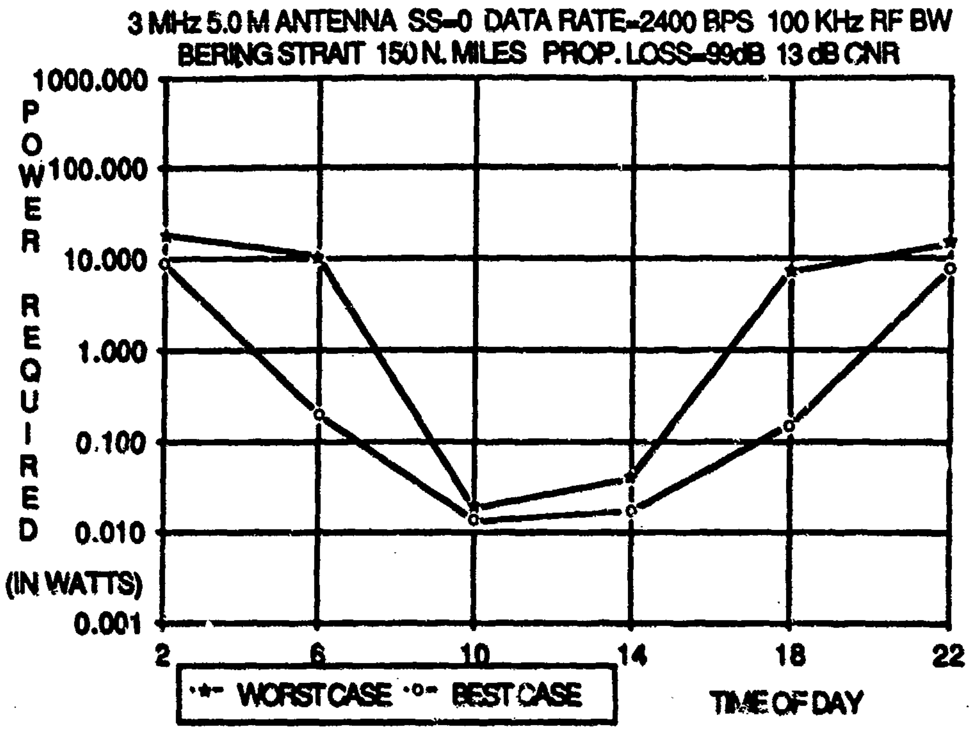
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	53.1
0400-0800	53.2
0800-1200	43.0
1200-1600	49.5
1600-2000	56.0
2000-2400	53.7
BEST CASE	
0000-0400	40.2
0400-0800	44.7
0800-1200	38.0
1200-1600	43.2
1600-2000	47.0
2000-2400	45.5



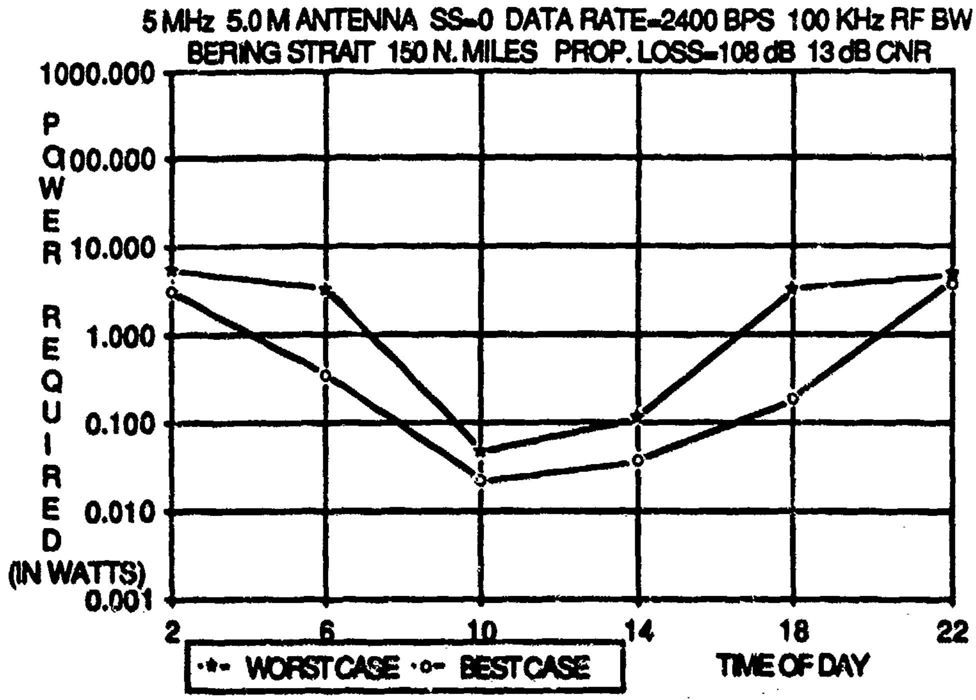
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
<u>WORST CASE</u>	
0000-0400	53.1
0400-0800	53.2
0800-1200	43.0
1200-1600	49.5
1600-2000	56.0
2000-2400	53.7
<u>BEST CASE</u>	
0000-0400	40.2
0400-0800	44.7
0800-1200	38.0
1200-1600	43.2
1600-2000	47.0
2000-2400	45.5

APPENDIX D

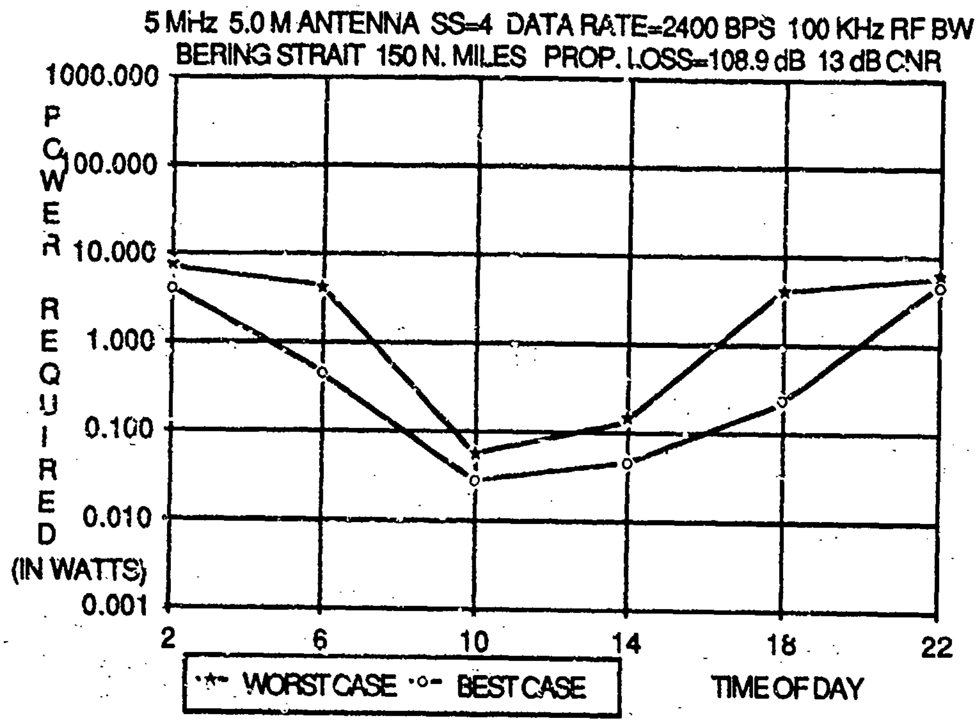
The figures in this appendix show the predictions of required driver power for the buoy antenna at a range of 278 km (150 n. miles) for a high latitude geographical location near the Bering Strait. A data rate of 2400 bits/sec and an RF bandwidth of 100 kHz are assumed. The required power is plotted as a function of time of day in units of 4-hour time blocks. A built-in limitation in the plotting software package prevented the time axis from spanning the full range of 0 to 24 hours; however, it should be understood that the full 24 hour time period is intended for the graphs. The highest set of connected points apply to the case of lowest seasonal noise while the lowest set of points apply to highest seasonal noise. The data below the graphs show the actual environmental noise values used in the calculations for each time block. The surface wave propagation attenuations used for this range as a function of frequency and sea state were shown previously in Appendix C, page C-1.



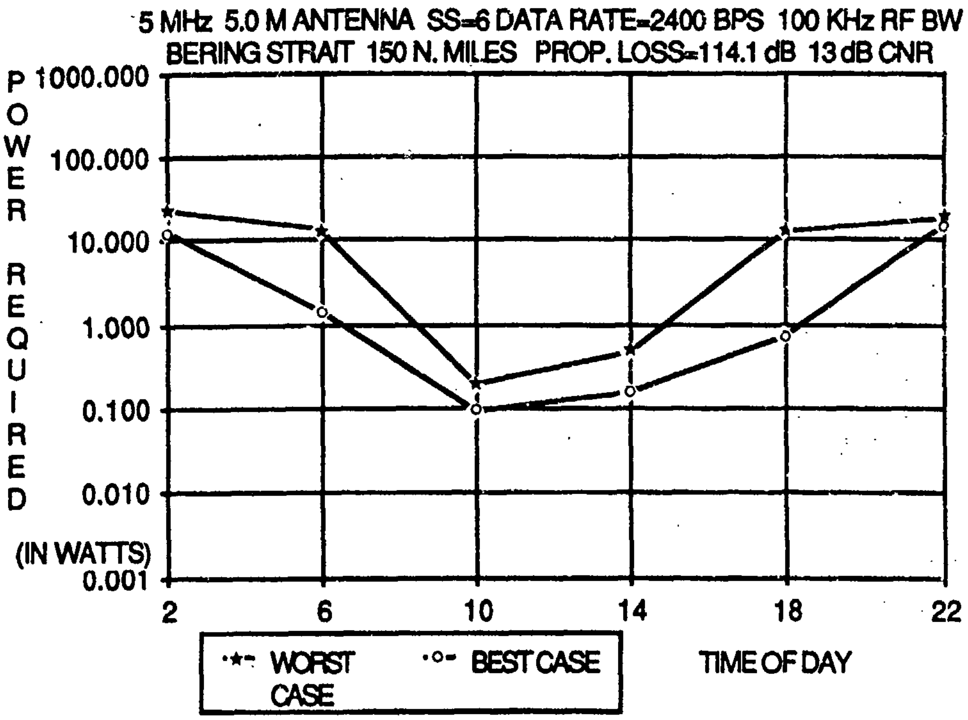
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	55.6
0400-0800	53.0
0800-1200	25.7
1200-1600	29.0
1600-2000	51.6
2000-2400	54.8
BEST CASE	
0000-0400	52.6
0400-0800	35.8
0800-1200	24.0
1200-1600	25.3
1600-2000	34.8
2000-2400	51.9



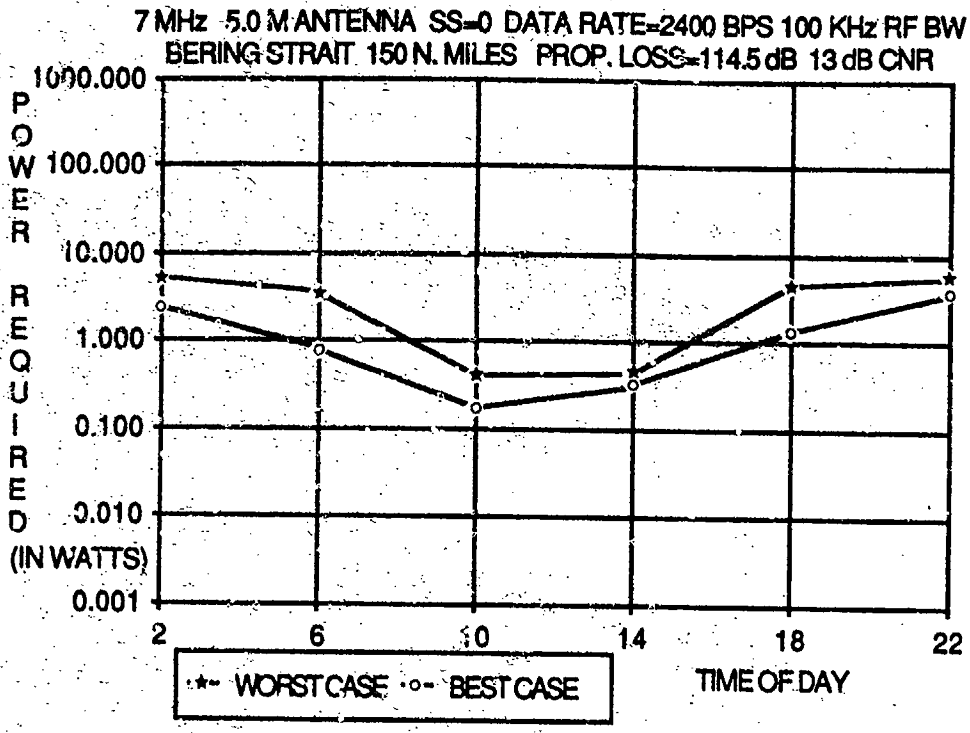
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	51.5
0400-0800	49.2
0800-1200	30.7
1200-1600	34.6
1600-2000	49.2
2000-2400	50.9
BEST CASE	
0000-0400	49.1
0400-0800	39.5
0800-1200	27.5
1200-1600	29.8
1600-2000	36.7
2000-2400	49.8



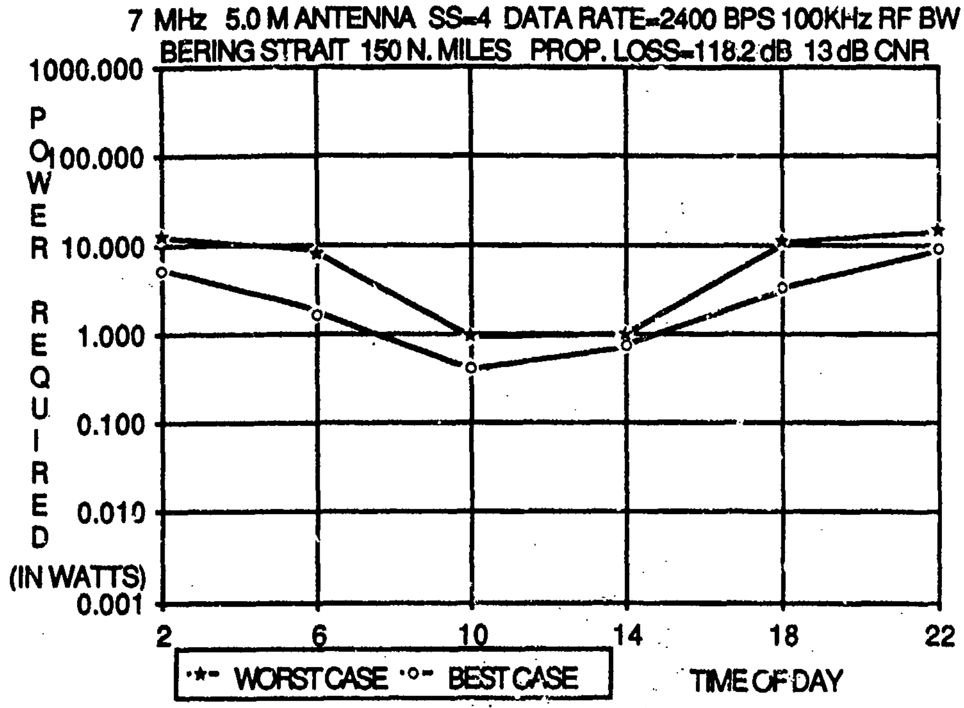
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	51.5
0400-0800	49.2
0800-1200	30.7
1200-1600	34.6
1600-2000	49.2
2000-2400	50.9
BEST CASE	
0000-0400	49.1
0400-0800	39.5
0800-1200	27.5
1200-1600	29.8
1600-2000	36.7
2000-2400	49.8



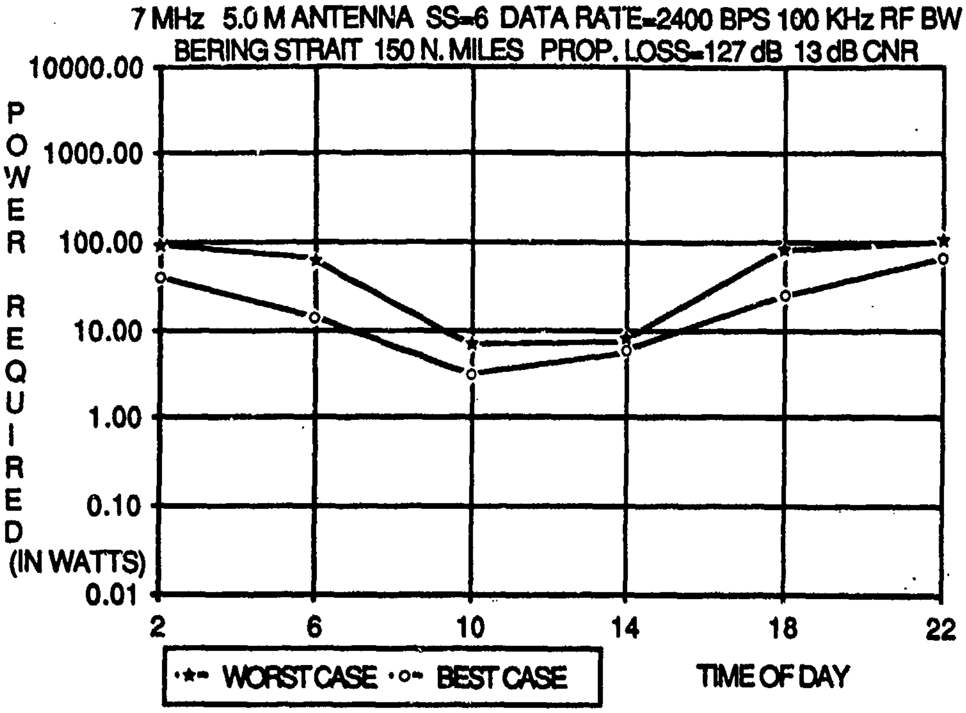
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	51.5
0400-0800	49.2
0800-1200	30.7
1200-1600	34.6
1600-2000	49.2
2000-2400	50.9
BEST CASE	
0000-0400	49.1
0400-0800	39.5
0800-1200	27.5
1200-1600	29.8
1600-2000	36.7
2000-2400	49.8



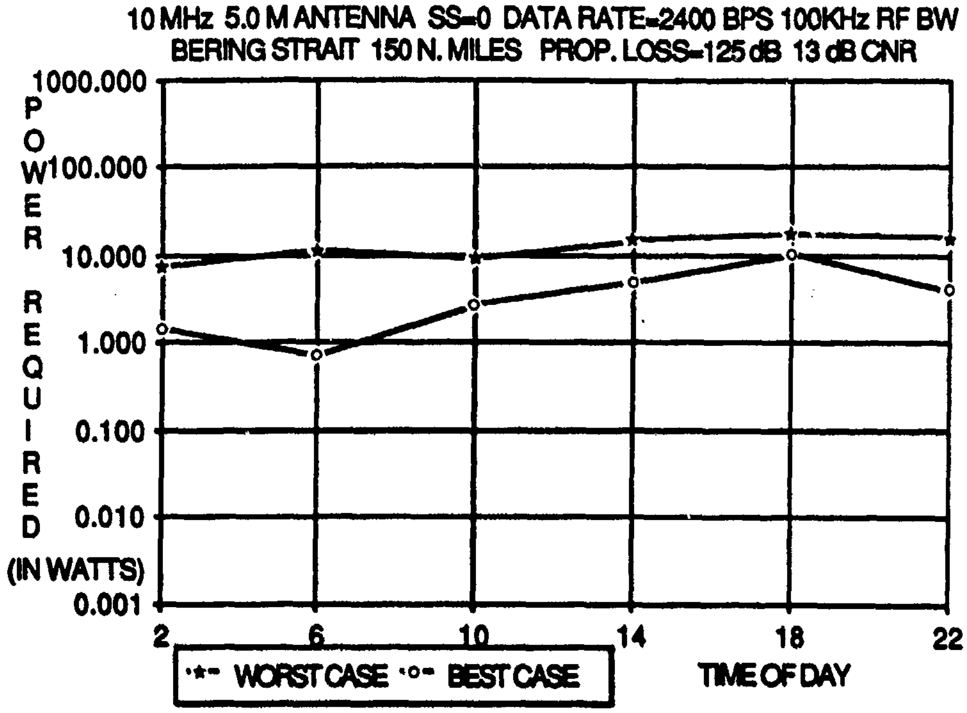
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	46.7
0400-0800	45.0
0800-1200	35.5
1200-1600	36.0
1600-2000	46.2
2000-2400	47.4
BEST CASE	
0000-0400	43.2
0400-0800	38.5
0800-1200	32.0
1200-1600	34.7
1600-2000	41.0
2000-2400	45.5



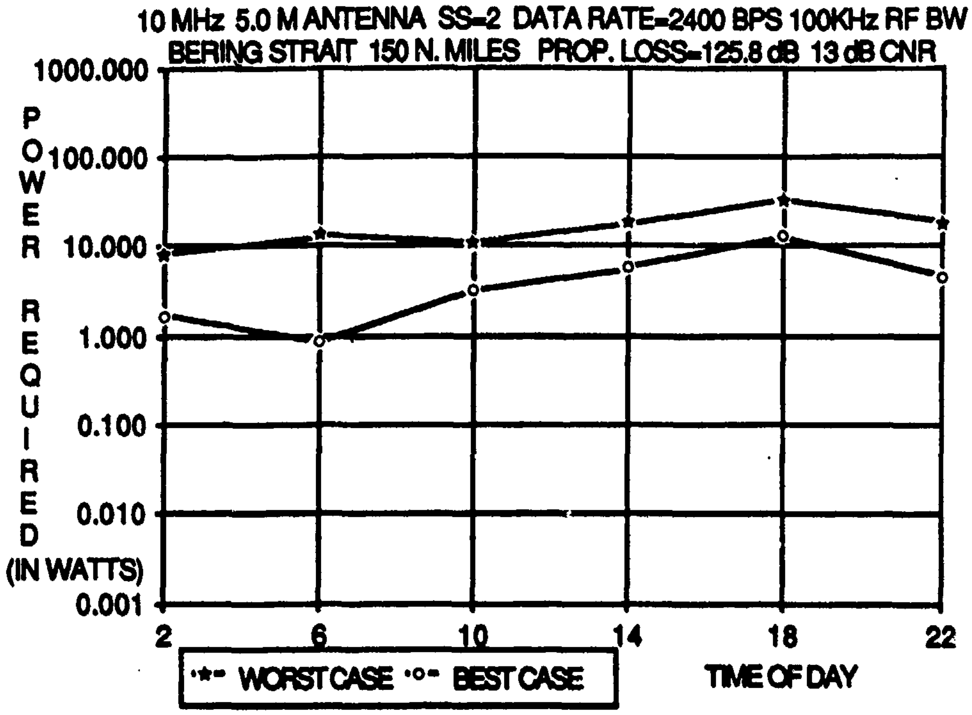
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	46.7
0400-0800	45.0
0800-1200	35.5
1200-1600	36.0
1600-2000	46.2
2000-2400	47.4
BEST CASE	
0000-0400	43.2
0400-0800	38.5
0800-1200	32.0
1200-1600	34.7
1600-2000	41.0
2000-2400	45.5



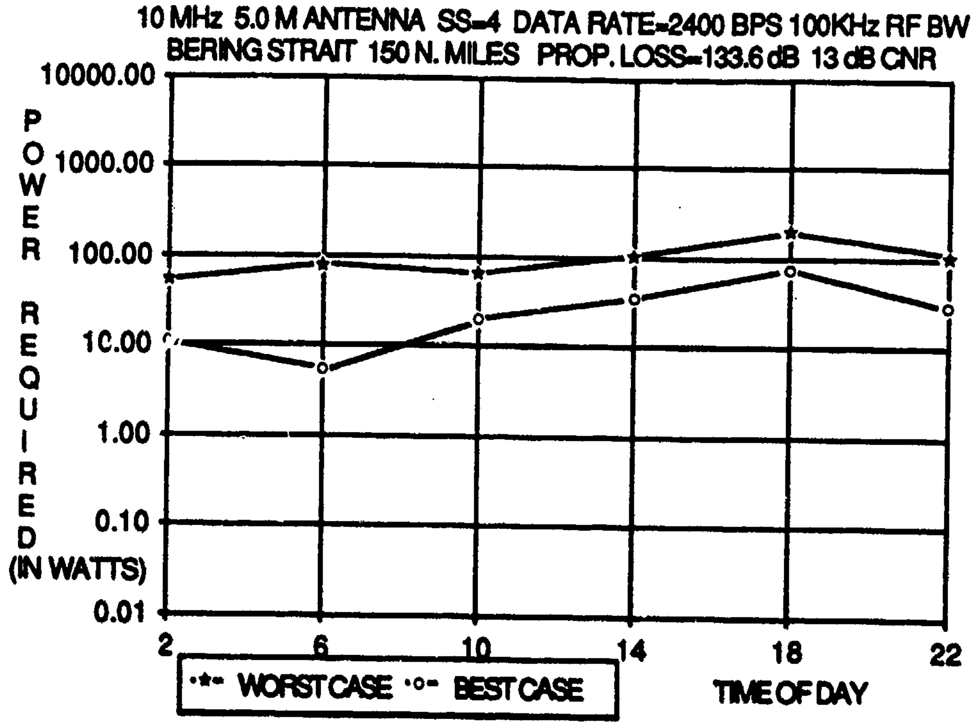
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
<u>WORST CASE</u>	
0000-0400	46.7
0400-0800	45.0
0800-1200	35.5
1200-1600	36.0
1600-2000	46.2
2000-2400	47.4
<u>BEST CASE</u>	
0000-0400	43.2
0400-0800	38.5
0800-1200	32.0
1200-1600	34.7
1600-2000	41.0
2000-2400	45.5



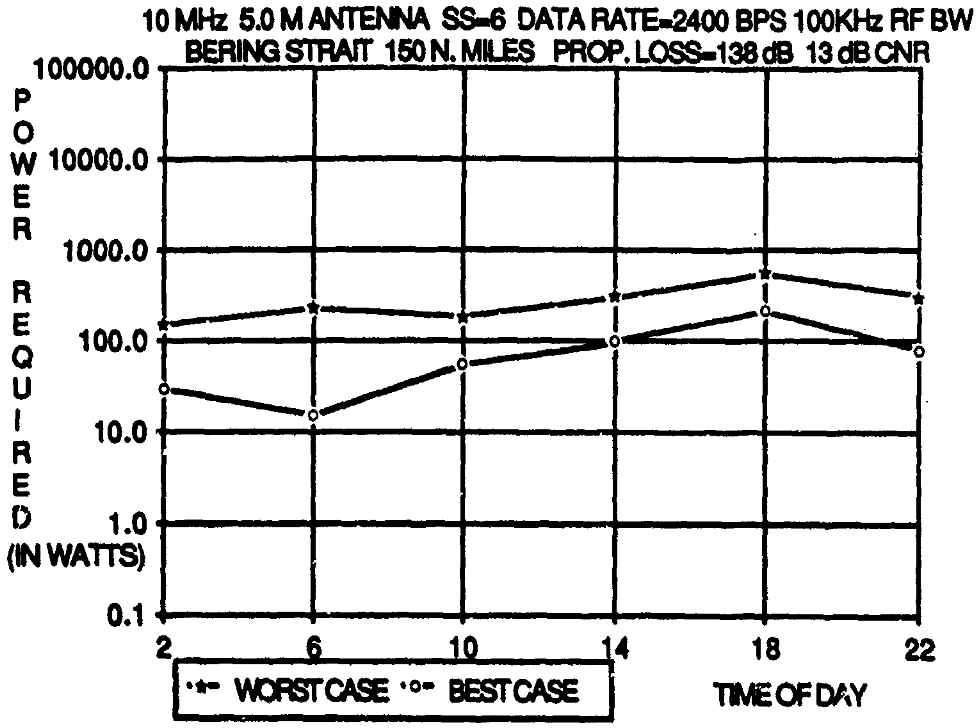
TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	38.1
0400-0800	40.1
0800-1200	39.1
1200-1600	41.2
1600-2000	43.9
2000-2400	41.3
BEST CASE	
0000-0400	31.2
0400-0800	28.1
0800-1200	33.9
1200-1600	36.5
1600-2000	39.8
2000-2400	35.4



TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	38.1
0400-0800	40.1
0800-1200	39.1
1200-1600	41.2
1600-2000	43.9
2000-2400	41.3
BEST CASE	
0000-0400	31.2
0400-0800	28.1
0800-1200	33.9
1200-1600	36.5
1600-2000	39.8
2000-2400	35.4



TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	38.1
0400-0800	40.1
0800-1200	39.1
1200-1600	41.2
1600-2000	43.9
2000-2400	41.3
BEST CASE	
0000-0400	31.2
0400-0800	28.1
0800-1200	33.9
1200-1600	36.5
1600-2000	39.8
2000-2400	35.4

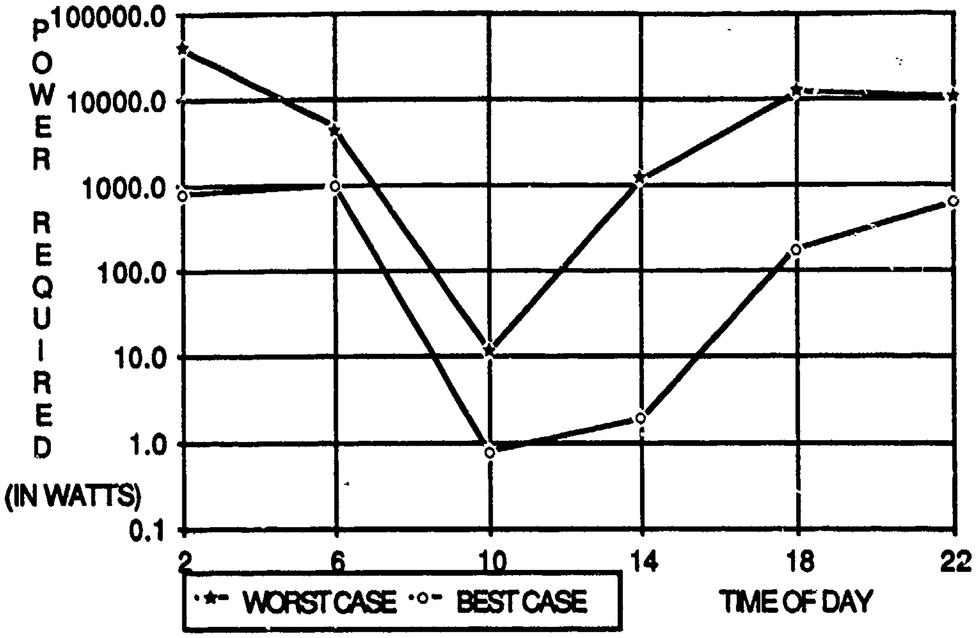


TIME BLOCK	FA (ENV. NOISE FIGURE (dB))
WORST CASE	
0000-0400	38.1
0400-0800	40.1
0800-1200	39.1
1200-1600	41.2
1600-2000	43.9
2000-2400	41.3
BEST CASE	
0000-0400	31.2
0400-0800	28.1
0800-1200	33.9
1200-1600	36.5
1600-2000	39.8
2000-2400	35.4

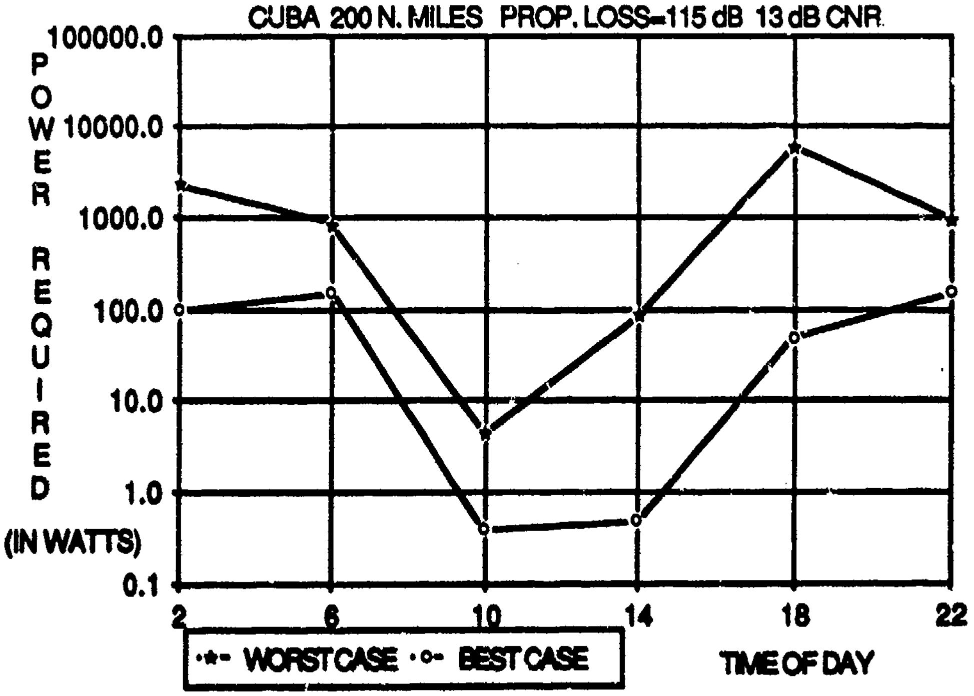
APPENDIX E

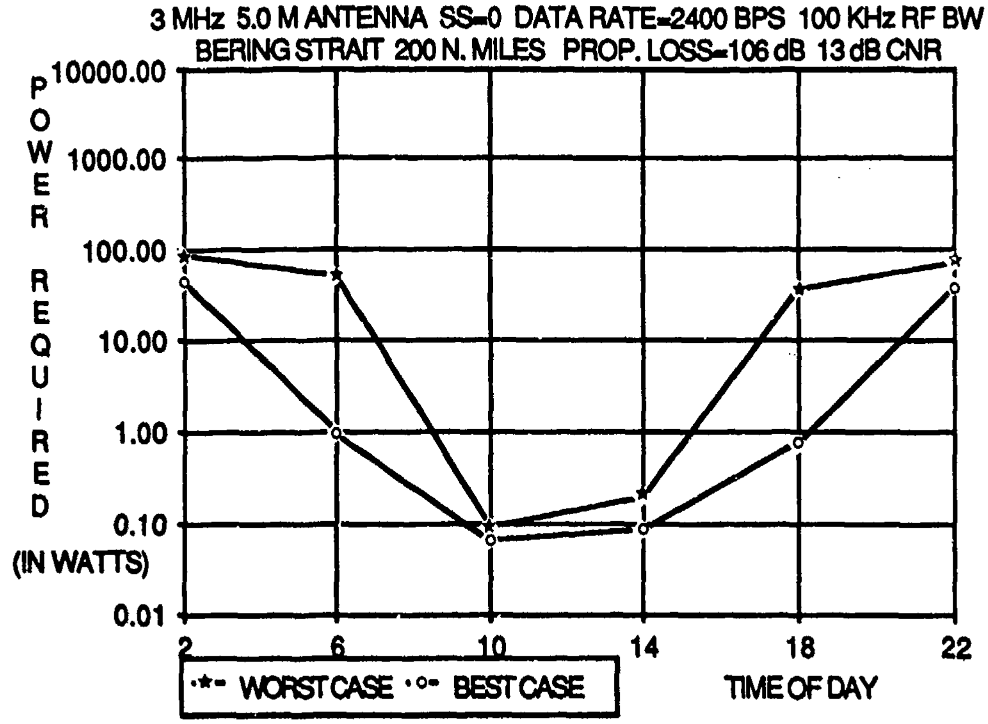
This appendix shows the diurnal variation of required driver power at a range of 370 km (200 n. miles) for the Cuba and Bering Strait locations at frequencies of 3 and 5 MHz and sea state zero. A 100 kHz RF bandwidth is assumed.

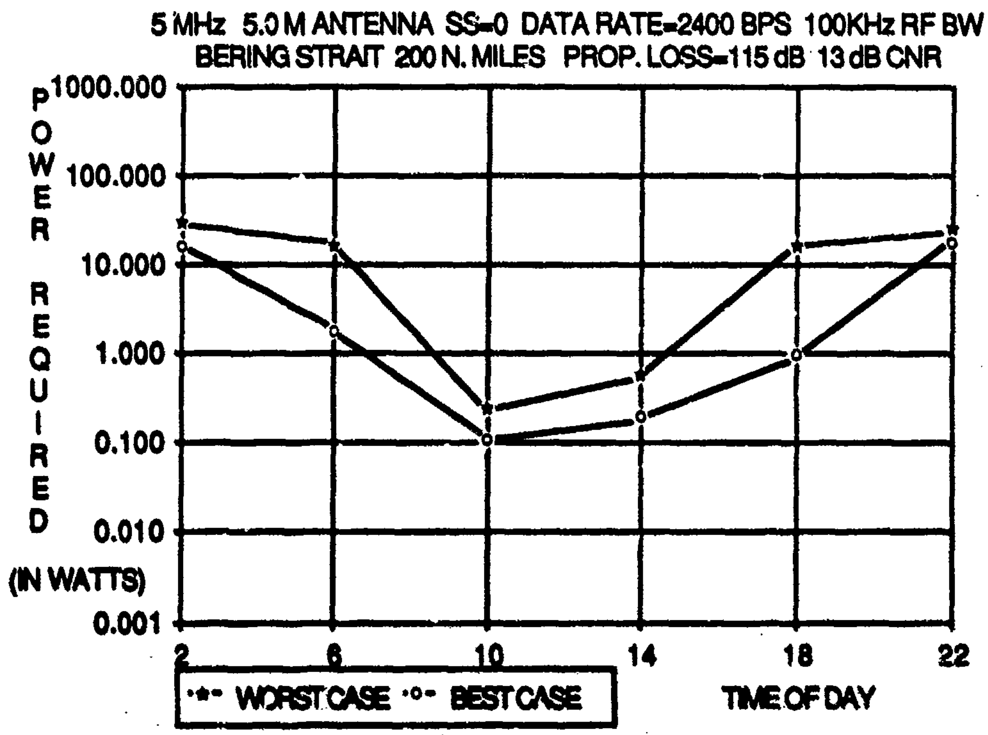
3 MHz 5.0 M ANTENNA SS=0 DATA RATE=2400 BPS 100 KHz RF BW
CUBA 200 N. MILES PROP. LOSS=106 dB 13 dB CNR



5 MHz 5.0 M ANTENNA SS=0 DATA RATE=2400 BPS 100KHz RF BW
CUBA 200 N. MILES PROP. LOSS=115 dB 13 dB CNR

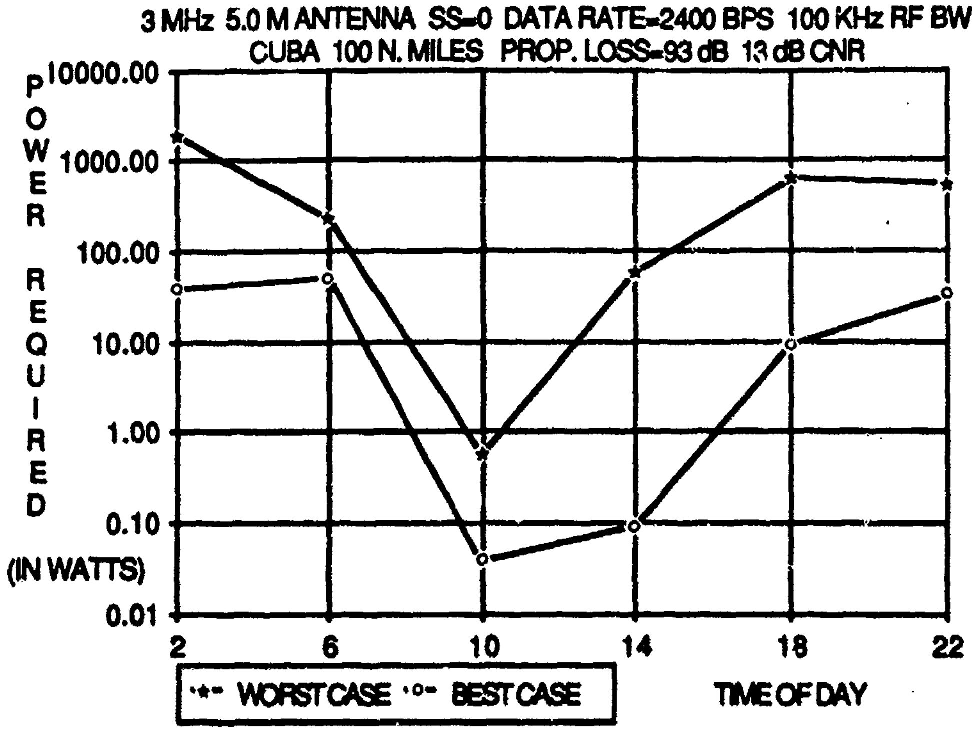


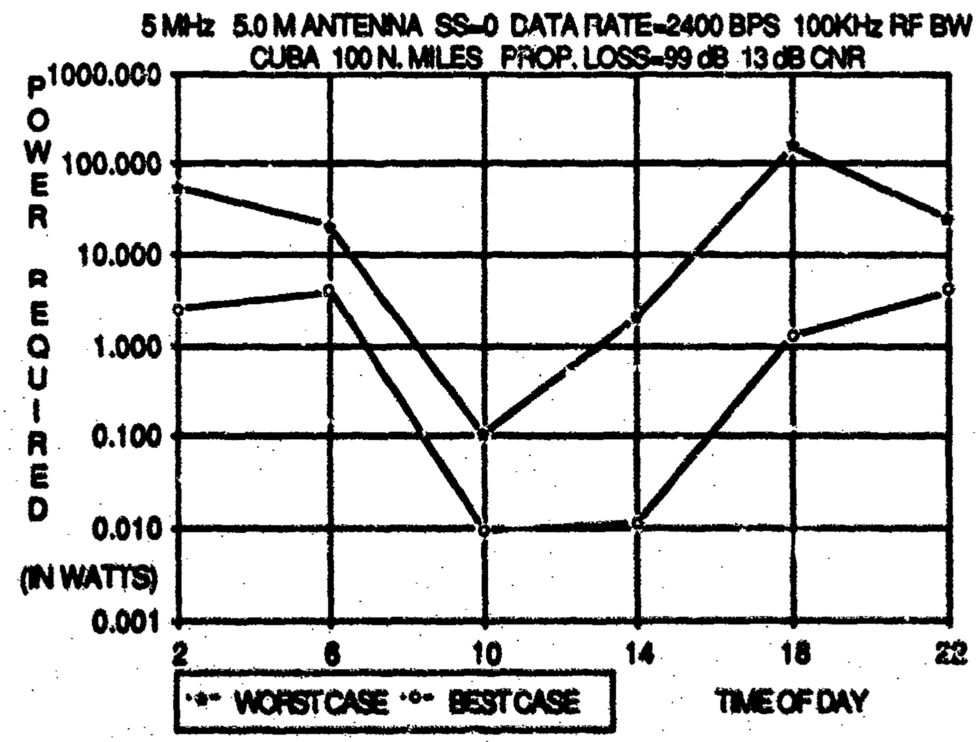

3 MHz 5.0 M ANTENNA SS=0 DATA RATE=2400 BPS 100 KHz RF BW
BERING STRAIT 200 N. MILES PROP. LOSS=106 dB 13 dB CNR
POWER REQUIRED (IN WATTS)
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01
2
6
10
14
18
22
WORST CASE
BEST CASE
TIME OF DAY

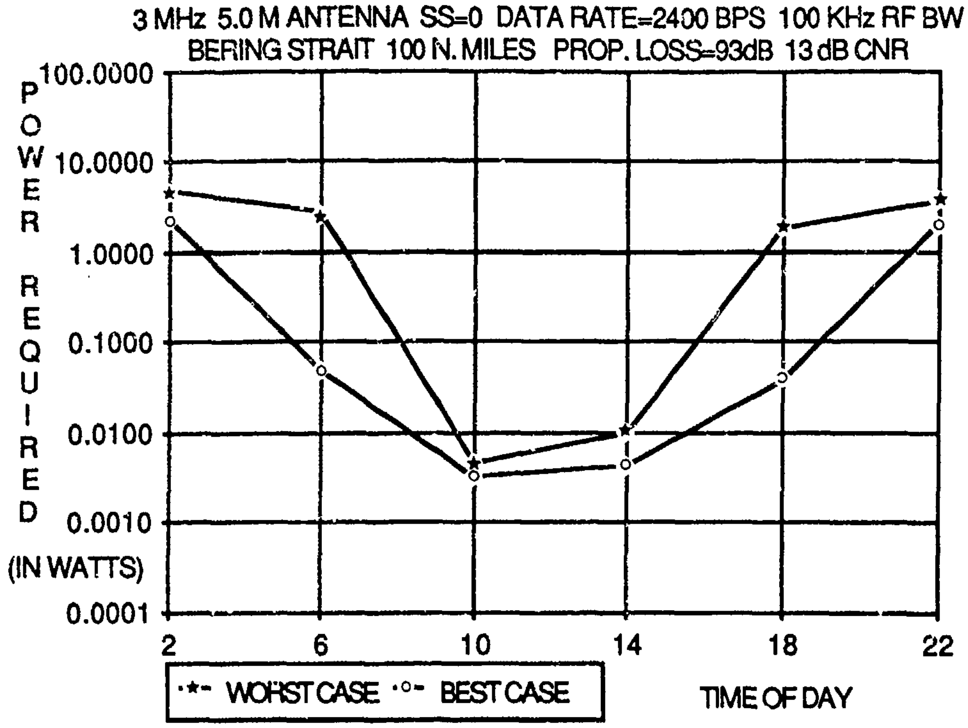

5 MHz 5.0 M ANTENNA SS=0 DATA RATE=2400 BPS 100KHz RF BW
BERING STRAIT 200 N. MILES PROP. LOSS=115 dB 13 dB CNR
POWER REQUIRED (IN WATTS)
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
2
6
10
14
18
22
WORST CASE
BEST CASE
TIME OF DAY

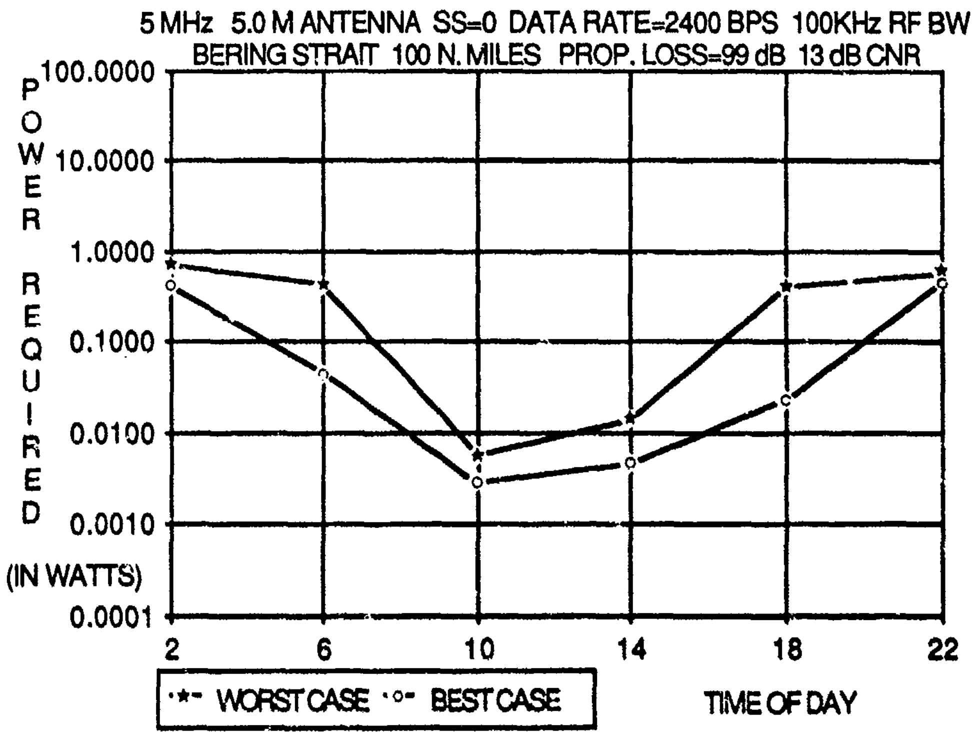
APPENDIX F

This appendix shows the diurnal variation of required driver power at a range of 185 km (100 n. miles) for the Cuba and Bering Strait locations at frequencies of 3 and 5 MHz and sea state zero. A 100 kHz RF bandwidth is assumed.


3 MHz 5.0 M ANTENNA SS=0 DATA RATE=2400 BPS 100 KHz RF BW
CUBA 100 N. MILES PROP. LOSS=93 dB 13 dB CNR
POWER REQUIRED (IN WATTS)
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01
2
6
10
14
18
22
WORST CASE
BEST CASE
TIME OF DAY


5 MHz 5.0 M ANTENNA SS=0 DATA RATE=2400 BPS 100KHz RF BW
CUBA 100 N. MILES PROP. LOSS=99 dB 13 dB CNR
POWER REQUIRED (IN WATTS)
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
2
6
10
14
18
22
WORST CASE
BEST CASE
TIME OF DAY

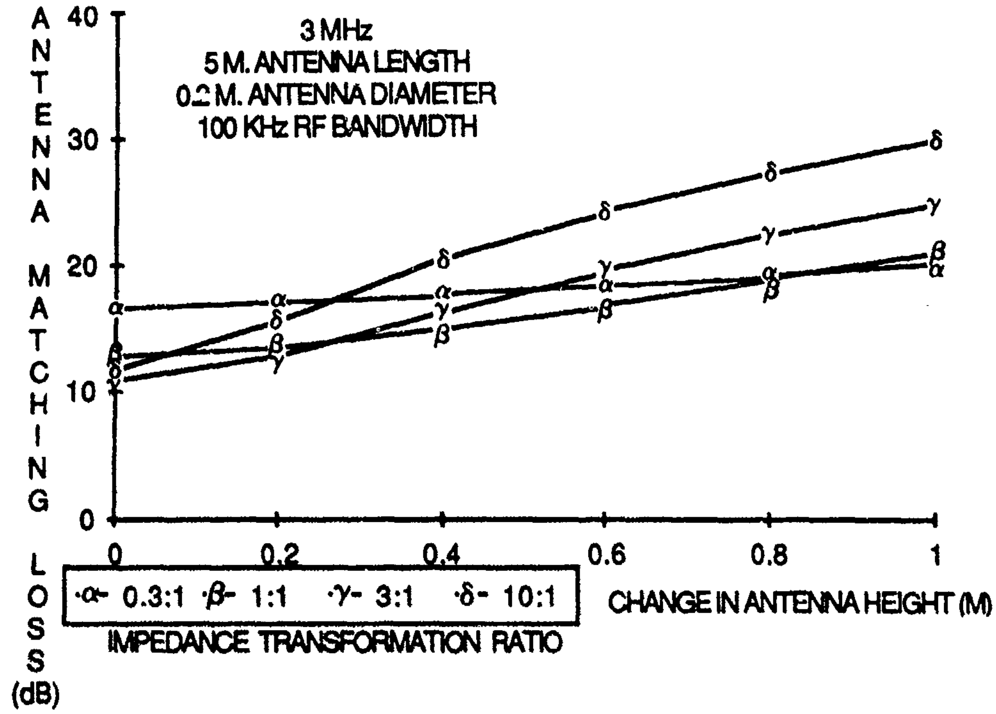

3 MHz 5.0 M ANTENNA SS=0 DATA RATE=2400 BPS 100 KHz RF BW
BERING STRAIT 100 N. MILES PROP. LOSS=93dB 13 dB CNR
POWER REQUIRED (IN WATTS)
100.0000
10.0000
1.0000
0.1000
0.0100
0.0010
0.0001
2
6
10
14
18
22
WORST CASE
BEST CASE
TIME OF DAY


5 MHz 5.0 M ANTENNA SS=0 DATA RATE=2400 BPS 100KHz RF BW
BERING STRAIT 100 N. MILES PROP. LOSS=99 dB 13 dB CNR
POWER REQUIRED (IN WATTS)
100.0000
10.0000
1.0000
0.1000
0.0100
0.0010
0.0001
2
6
10
14
18
22
WORST CASE
BEST CASE
TIME OF DAY

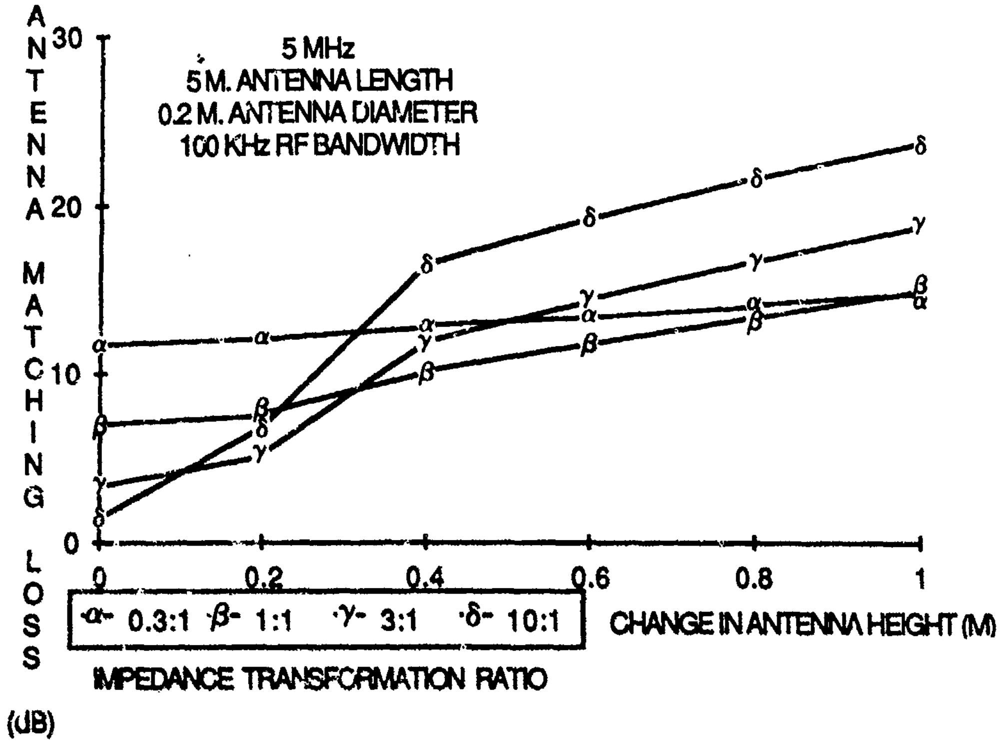
6-1

APPENDIX G

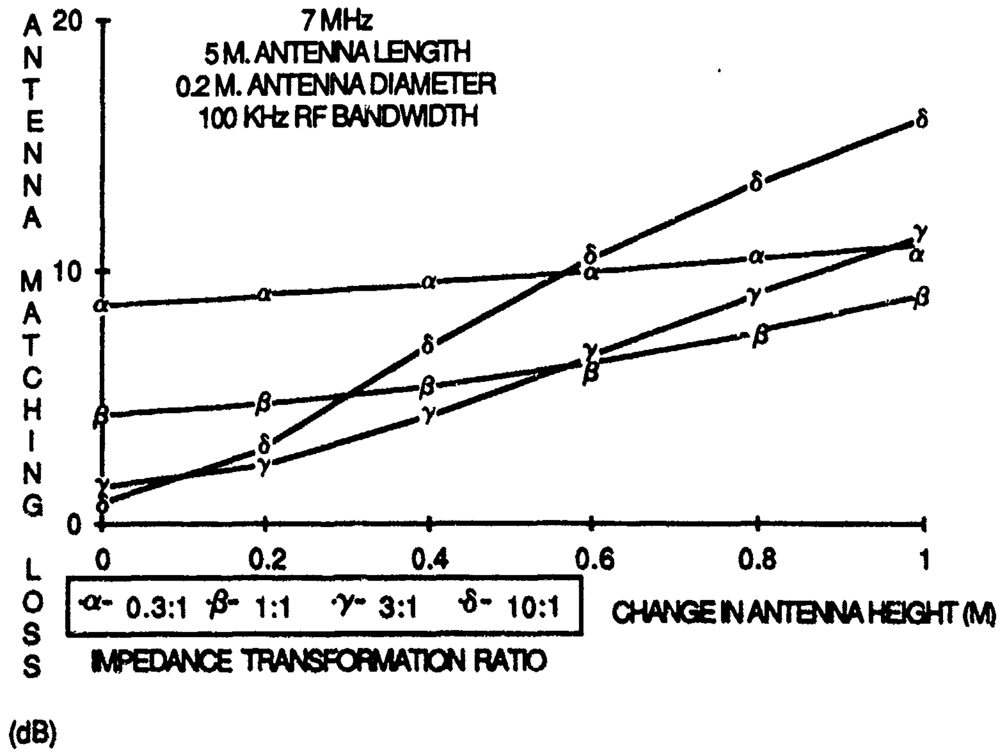
The graphs in this appendix show the effect of variation in the height of the electrical feedpoint of the antenna (monopole, 5 meter height, 0.2 meter thickness) relative to seawater for 10 and 100 kHz RF bandwidth. The simplifying assumptions made to anaylze this problem (see end of Section II) probably lead to an underestimate of the severity of this phenomenon. Therefore, these results should be treated as a lower bound to the additional loss that will be encountered in the real world from antenna bobbing. At 5 MHz and above, the results are nearly identical for either 10 or 100 kHz bandwidth.



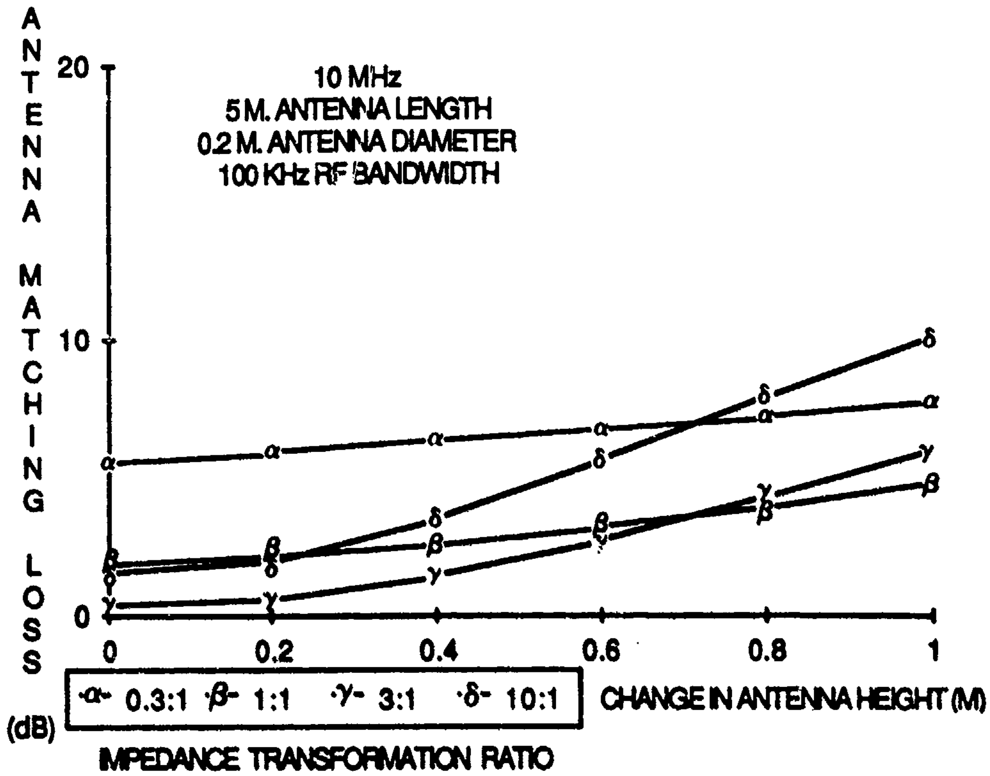
Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



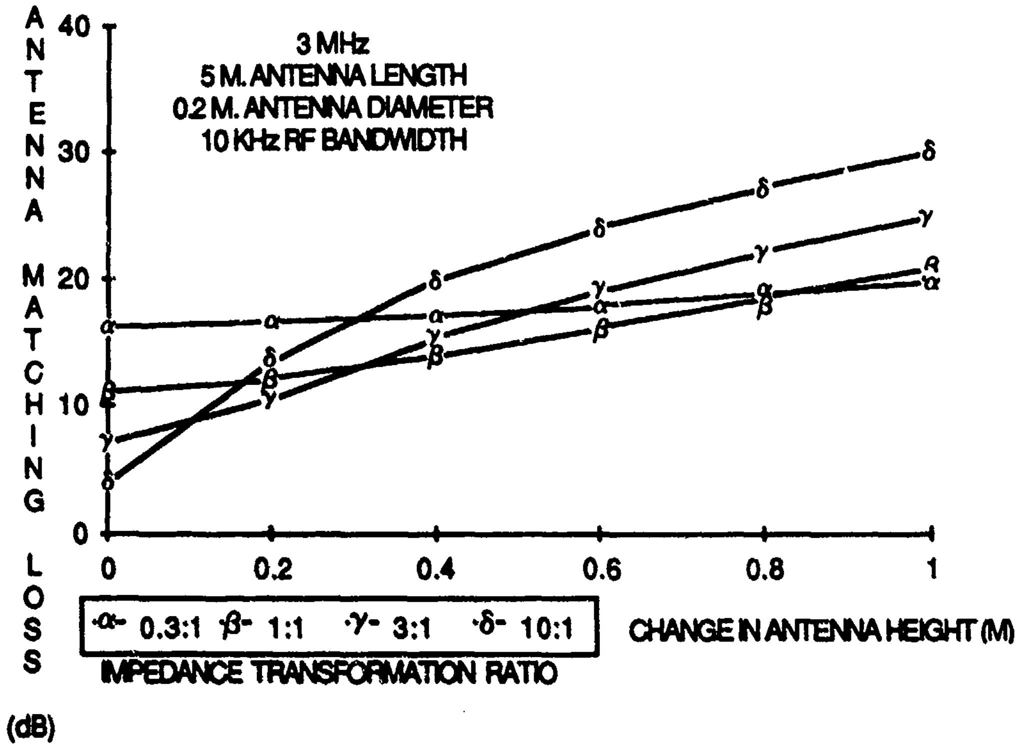
Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



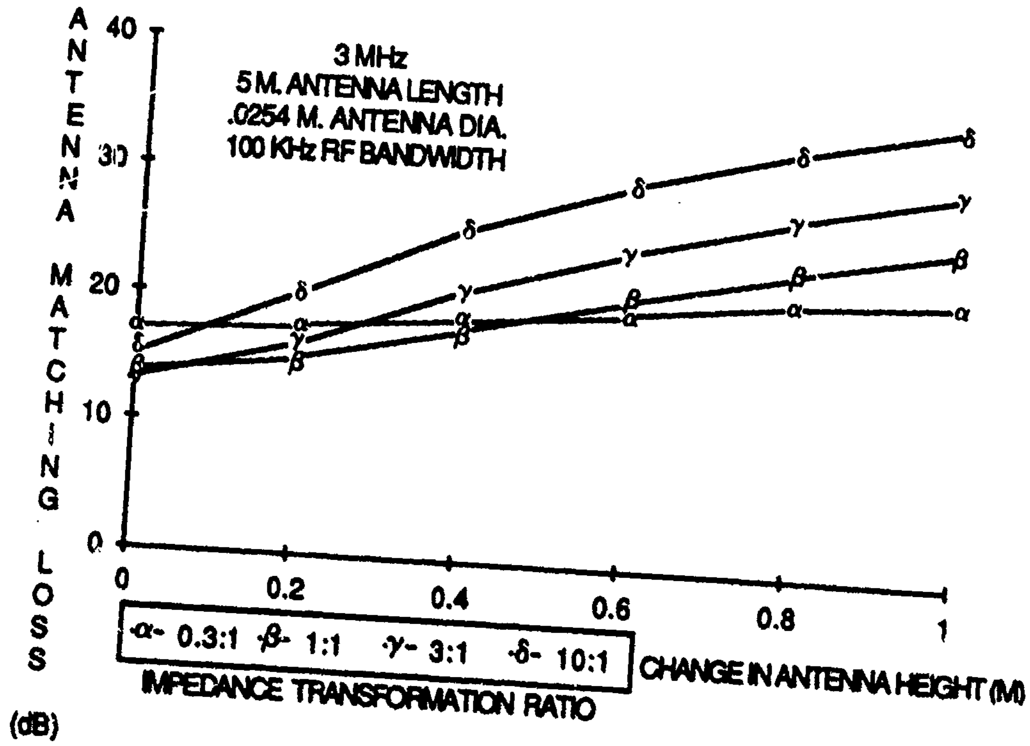
Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



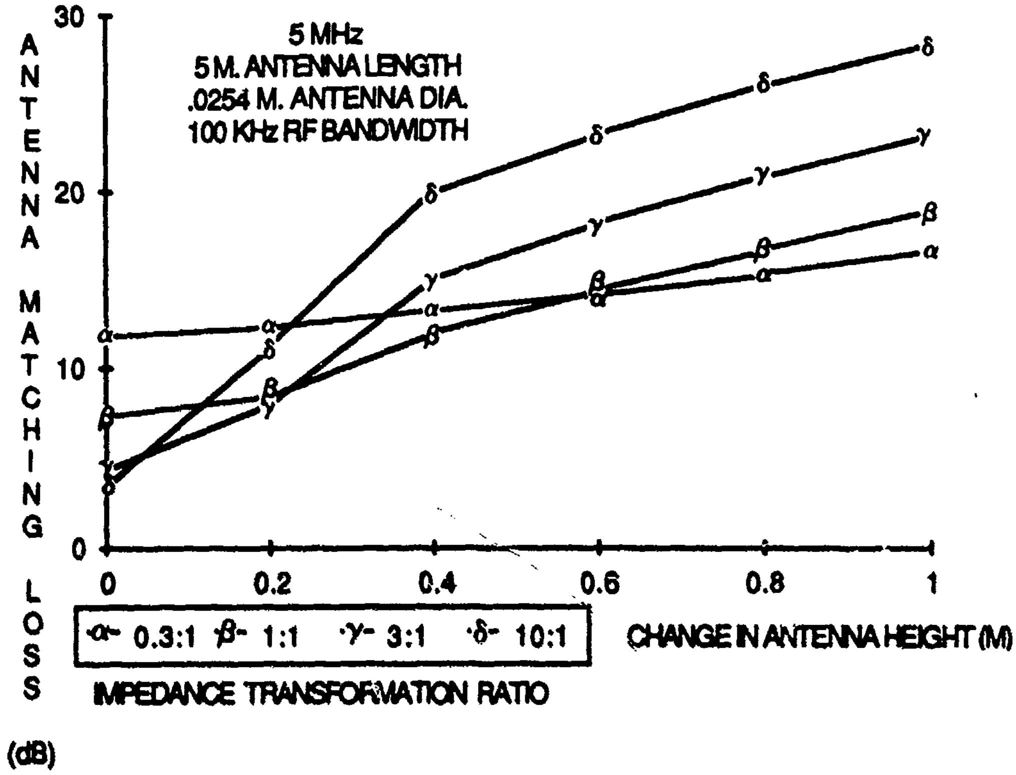
Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.

APPENDIX H

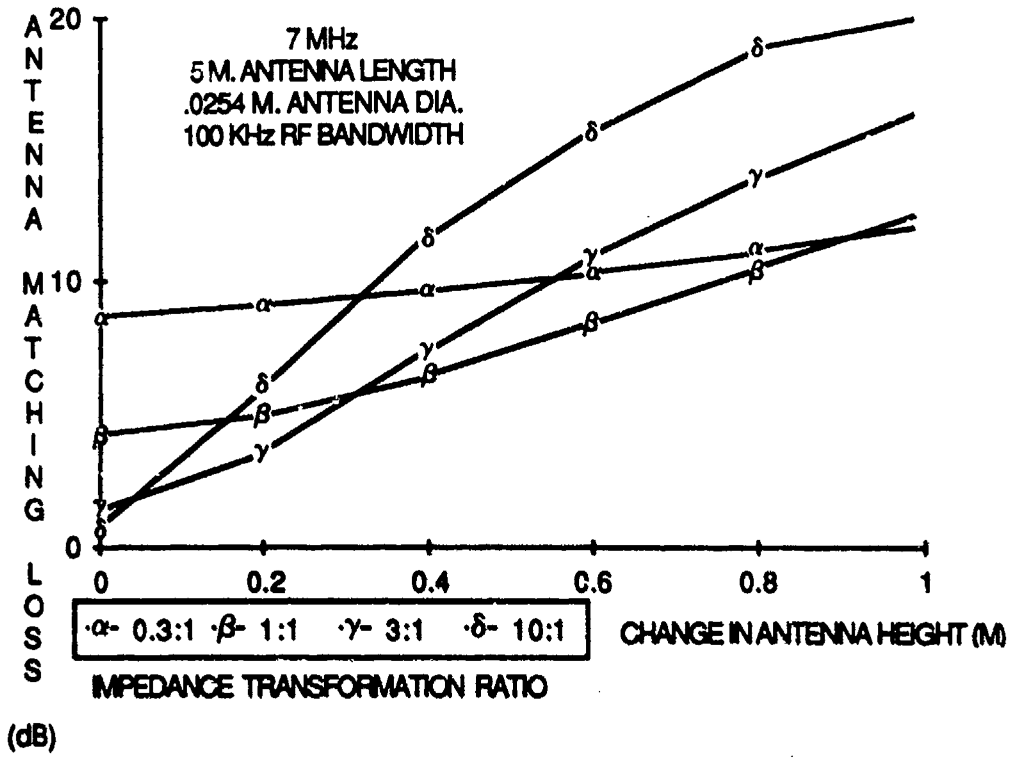
The graphs in this appendix show the effect of variation in the height of the electrical feedpoint of the antenna (monopole, 5 meter height, 0.0254 meter thickness) relative to seawater for 10 and 100 kHz RF bandwidth. The simplifying assumptions made to anaylze this problem (see end of Section II) probably lead to an underestimate of the severity of this phenomenon. Therefore, these results should be treated as a lower bound to the additional loss that will be encountered in the real world from antenna bobbing.



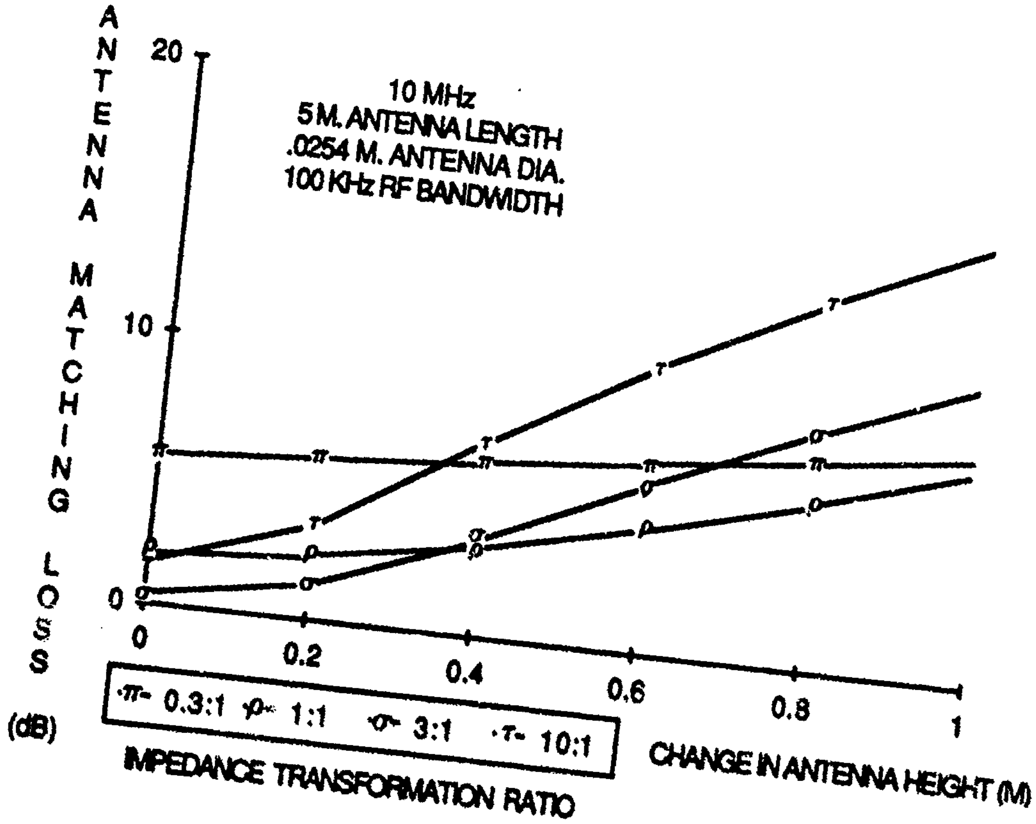
Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



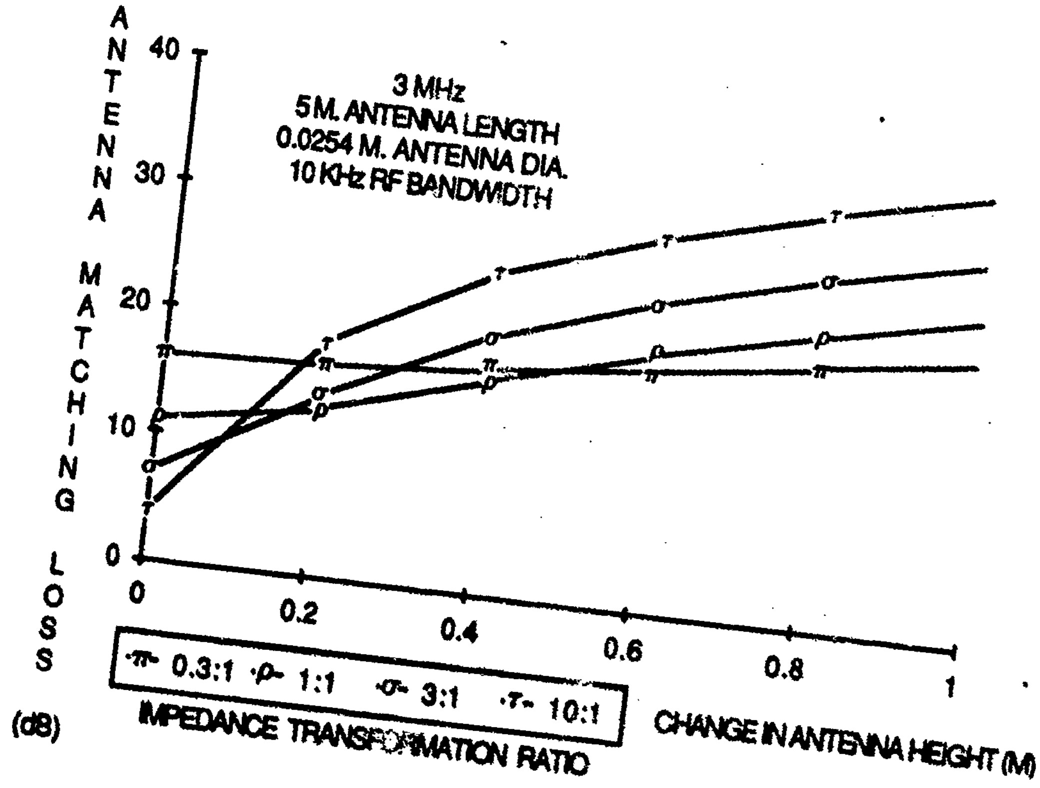
Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



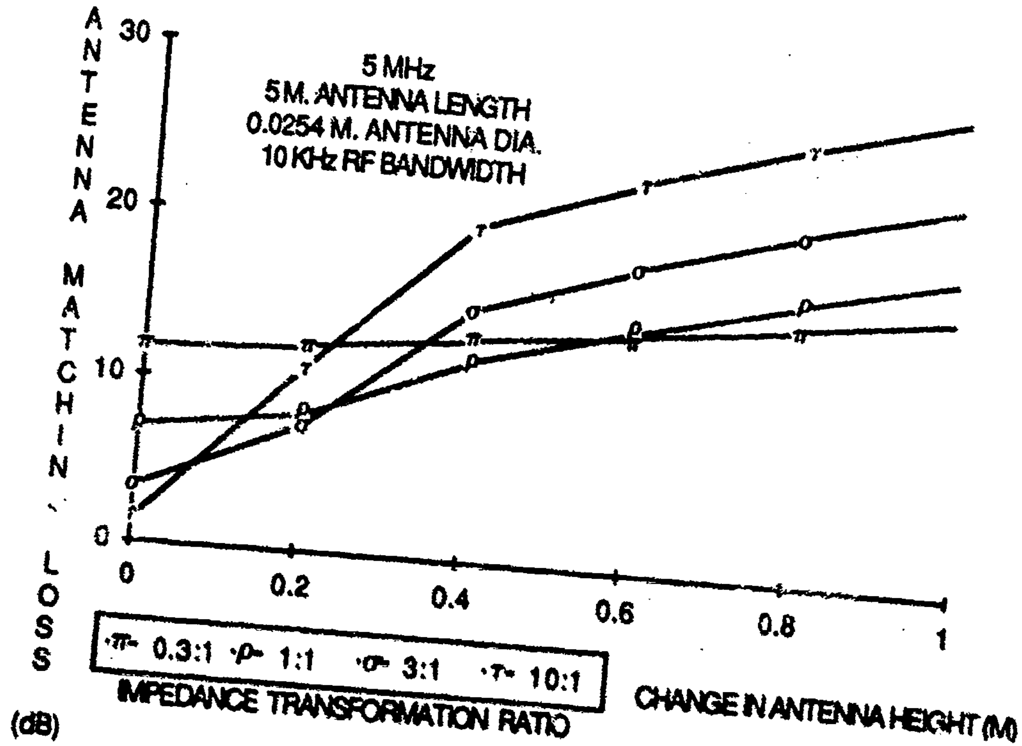
Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



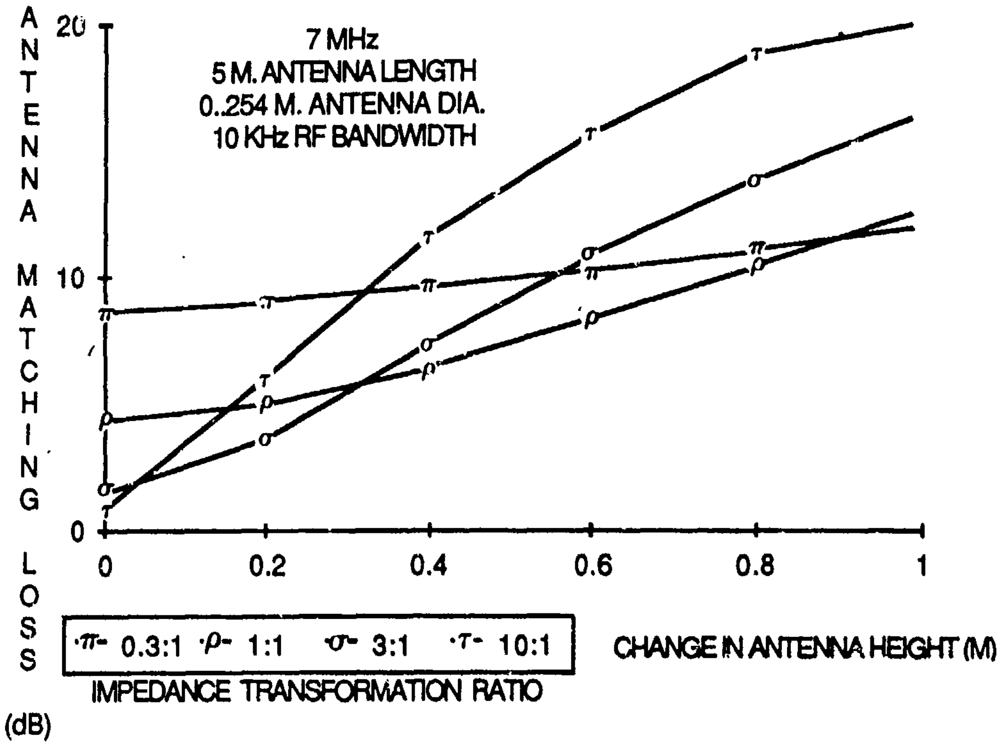
Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



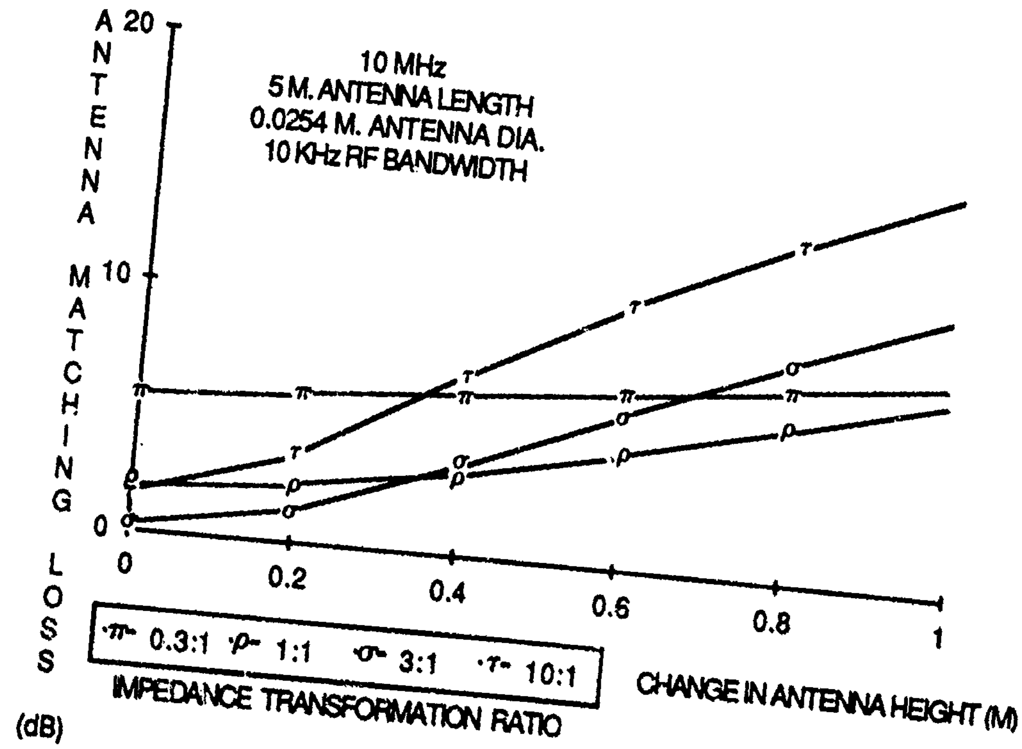
Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.



Optimistic assessment of the effect of variations in the height of the electrical feedpoint of the antenna relative to the seawater (only depressions were analyzed). It is assumed that a dielectric coating has been applied to the antenna by a technique that makes the feedpoint height change appear like a shortening (lengthening) of the antenna with a corresponding lengthening (shortening) of the feeder transmission line. The impedance matching circuitry was optimized for nondepressed/extended feedpoint height for fixed impedance ratios. A 10:1 ratio implies a step-down of the driver/receiver impedance by a factor of 10.